Investigating the relationship between EEXI, CII and vessel values in the oil tanker and dry bulk carrier sectors

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ABSTRACT:

This paper examines the effect of Carbon Intensity Indicator (CII), Annual Efficiency Ratio (AER), and Energy Efficiency Existing Ship Index (EEXI) on second-hand ship prices. The relationship between these indices and vessel values is investigated, using unique data from sales transactions of Aframax and Handymax tankers, and Handysize bulk carriers between 2020 and mid-2023 obtained from VesselsValue. Hypothesis testing is conducted and hedonic price regression models are used to examine the relationship between energy efficiency and ship values. The results suggest that second-hand ships are priced differently in the second-hand market, depending on their CII rating. The AER and EEXI are significant determinants of ship prices with varying elasticities, depending on the ship type. Ship prices with lower EEXI and AER are valued higher and vice versa. These findings are important for industry stakeholders in the maritime sector and policy makers of environmental regulations in shipping.

KEYWORDS:

Vessel price; **tankers**; **bulk carriers**; **CII**; **EEXI**

1. INTRODUCTION

Different efficiency profiles of ships can potentially influence the price they command in the second-hand market. For example, a more energy efficient ship or a ship which uses alternative fuels may be valued higher than a less energy efficient ship. The same also holds true for the relationship between carbon intensity ratings of ships and values. Energy efficiency of ships has become more important in recent years, driven by technological improvements, operational measures, managerial approaches, and most importantly, regulatory and policy changes towards emissions reductions.

Technological improvements refer to the size of the ship, hull shape and coating, air lubrication, hybrid propulsion, and energy saving devices amongst others, whilst operational measures include speed and voyage optimisation, capacity utilisation, and the use of alternative fuel types (Bouman et al. 2017; Mallouppas and Yfantis 2021; Ampah et al. 2021). The environmental management strategy of shipping companies is also found to contribute to better financial performance by adopting a proactive green shipping strategy when investing or operating shipping assets (Alexandrou et al. 2021).

Moreover, the growing emphasis on reducing the environmental impact of shipping puts pressure on shipowners, charterers, banks, and institutional investors to view and handle climate change as a financial risk. Ships serve as the primary assets in shipping company valuations, and any decline in their values poses a business risk for investors involved in these companies (Drobetz et al. 2016; Alexandridis et al. 2018). Hence, capital providers will play more and more a significant role by financing the construction of low or zero emissions new ships or the retrofitting of second-hand vessels (Poseidon Principles 2024).

Most importantly from a regulatory point of view, emissions reductions policies implemented by the International Maritime Organisation (IMO) influence investments in both new and second-hand ships. The IMO recently revised its Initial Strategy on Reduction of Greenhouse gas emissions (GHG) from Ships by adopting the 2023 IMO Strategy on Reduction of GHG Emissions from Ships in the 80th session of the Marine Environment Protection Committee (MEPC) (IMO 2024a). The revised strategy aims at net zero emissions from international shipping around 2050, an increase of lower GHG emissions technologies and fuels, and sets specific targets for the decline of the carbon intensity of international shipping as well as the carbon intensity of individual ships through the improvement of the energy efficiency of new and existing ships (IMO 2024a). To this end, two short-term measures were adopted in 2021 as part of the MEPC 76 session, namely the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII), which entered into force in 2023. The EEXI is a technical measure aiming at improving the technical efficiency of a ship compared to certain baselines, whereas the CII is an operational measure, aiming at rating the operational performance of a ship against specific target rates, both referring to existing ships (IMO 2024b).

The entry into force of these two measures and the reporting of annual ratings for individual ships will have a direct impact on how ships are operated and the technologies adopted to improve energy efficiency and reduce emissions. Different ratings for ships across the various shipping sectors and sub-sectors can potentially lead to multi-tiered second-hand markets, depending on the band of ratings they will attain every year. This is expected to influence ship values through future charter rates and costs, since the present value of a ship's price is a function of present charter rates, costs, age, and expectations about future charter rates and costs. There is some evidence from industry analysts that the number of transactions in the second-hand markets for ships that attained lower CII ratings was lower than that for ships included in higher bands of the CII index about three months after the CII entered into force in 2023 (VesselsValue 2023).

There is a very small number of studies reporting empirical research on the impact of energy efficiency on ship prices (Adland et al. 2018; Adland et al. 2023). These studies included efficiency-related variables in their analysis, such as speed, fuel consumption at the design speed, a fuel efficiency index, and engine-related characteristics. However, the relationship between ship prices and carbon intensity indices adopted by the IMO has not been investigated in the literature so far. On the one hand, there is high volatility in the second-hand markets where ship values change rapidly based on expectations about future market conditions. On the other hand, the mandatory reporting of annual emissions ratings is expected to influence ship values depending on the annual efficiency profile of the individual ships.

This paper is the first to investigate, to the best of our knowledge, the relationship between EEXI and CII indices and vessel values in the second-hand market by focusing on the early period of the implementation of this regulation. More specifically, ship prices of Aframax and Handymax oil tankers, and Handysize dry bulk carriers are used in the analysis, given the high number of transactions in the second-hand market for those sub-sectors compared to other ship types and sizes during 2020-2023. Two sample *t*-tests are conducted, and hedonic price regression models are used, including relevant vessel attributes in the analysis to examine these relationships.

The remainder of this paper is structured as follows. The review of the relevant literature on the impact of energy efficiency in vessel values is provided in Section 2. The data and statistical methodology are presented in Section 3. The findings are then reported in Section 4. The discussion of the findings, as well as conclusions and future research opportunities are provided in Section 5.

2. LITERATURE REVIEW

The second-hand market, also known as the sale and purchase (S&P) market, is where ships are sold and bought depending on freight market conditions and the particular stage of the shipping freight cycle. Moreover, the second-hand market facilitates the entry and exit of investors in shipping markets through leveraging the cyclical nature of freight markets. The four major factors which determine the value of a vessel are freight rates, age, inflation, and expectations about future market conditions (Stopford 2009). Pruyn et al. (2011) conducted a review of the literature on value estimation of second-hand vessels spanning from 1991 to 2011. Although the majority of the studies identified in the review focus on the testing for the Efficient Market Hypothesis, there have been a small number of studies that focus on microeconomic factors of value formation in the second-hand markets.

Adland and Koekebakker (2007) examine vessel valuation in the second-hand market for Handysize bulk carriers, using a combination of macroeconomic factors, such as timecharter rates, and vessel-specific factors, such as age and size measured in deadweight tonnes (DWT) capacity. They find a negative relationship between age and second-hand prices, especially when moving towards older age tonnage where values converge to demolition price dynamics. Conversely, values are found to be an increasing function of ship size and of freight rates. Although the use of three explanatory variables reduces the pricing error compared to the univariate case, they point that more variables are needed to further explain vessel prices.

Adland and Köhn (2019) use the chemical tanker sector as a case to estimate vessel values in the second-hand market. They consider spot market earnings, newbuilding prices, and age, as well as several technical vessel-specific variables in the analysis. These include speed, number of cargo tanks, hull type (single/double), tank coating type, IMO classification type of chemical tankers and country of build. Moreover, two interaction variables consider cargo diversity and flexibility of cargo handling. They confirm the relationships between second-hand prices, age and charter rates found in Adland and Koekebakker (2007), whilst they find newbuilding prices to be an increasing function of second-hand prices. When it comes to technical factors, they find non-double hulled tankers to command lower prices, whilst there is a positive relationship between the interaction variables and speed and vessel values. Yet, tank coating is found to not affect values significantly, whereas the results on the impact of IMO classification type are mixed. Moreover, the country of build is found to matter as certain countries are perceived to build higher quality tonnage than other countries.

Adland et al. (2018) is the first study that considers energy efficiency related variables in the analysis along with other vessel-specific explanatory variables and market conditions. More specifically, the relationship between second-hand prices of Handysize bulk carriers and a number of explanatory variables is examined, including timecharter rates, age, size, capacity of cranes/derricks, speed, fuel consumption, a fuel efficiency index, the number of previous sales, buyer country and country of build. They confirm the relationships between ship prices, age and charter rates found in Adland and Koekebakker (2007) and Adland and Köhn (2019). Moreover, a positive relationship is found between ship values and a number of variables such as speed, cranes/derricks capacity, and the number of sales before the last transaction. The country of build is also found to affect ship prices, with a quality premium considered in the second-hand market, something which is also found in Adland and Köhn (2019) for chemical tankers. When it comes to fuel consumption and the fuel efficiency index, they found to have a negative relationship with ship values. However, the influence of these variables is reduced during good market conditions. These findings can be linked with the results from studies investigating the relationship between energy efficiency and freight rates (Agnolucci et al. 2014; Adland et al. 2017).

Adland et al. (2023) use various statistical techniques to examine Handysize ship values in the second-hand market. They consider various ship-specific variables in the models, similar to the previous studies mentioned here. This study also considers the orderbook to fleet ratio as a proxy for future supply expansion, an interest rate representing the cost of capital, and a number of engine-related variables, including engine manufacturer, main engine horsepower and rpm. Almost all variables are found to explain second-hand ship prices, with age and timecharter rate being the most important ones in most of the models. Fuel efficiency and fuel consumption were also found to be important explanatory variables amongst others.

Nam et al. (2022) examine the relationship between second-hand ship prices and age, size, timecharter rates and spot market earnings across a wide range of ship sizes in the tanker, bulk carrier and containership sectors. Moreover, they include the type of main engine, contract type and build country in the analysis. They find a negative relationship between age and ship values and a positive relationship between values and freight rates, with higher coefficients for larger sizes across all sectors and for both explanatory variables. Their results of the effect of tanker and bulk carrier sizes on ship values are mixed, whereas those of containerships are found to have a positive relationship with ship values. The results for timecharter rates indicate a positive relationship with ship values, although some size categories are found to be not statistically significant. Similar to other studies, the country of build is found to affect ship values, but results differ across ship types and sizes, whilst the same also holds true for the engine type variable.

Although the current literature considers major macroeconomic and microeconomic factors of vessel values determinants, they mainly focus on age, size and technical specifications. Whilst two studies included energy efficiency factors in their analysis, these refer to fuel and energy efficiency at the nominal level. Moreover, environmental regulations, especially with respect to emissions reductions have not been considered in the literature so far. These are expected to influence ship prices in the second-hand markets in many ways. The introduction of the EEXI and CII indices from the IMO in 2023 will ultimately put pressure on shipowners and operators to attain specific ratings every year (IMO 2024b). These developments could potentially lead to multi-tiered second-hand markets where values will be affected by the energy efficiency status of ships. Against this background, this paper contributes to the literature by investigating the influence of CII, AER, and EEXI on second-hand ship prices using a unique dataset from sales transactions in the second-hand market of Aframax and Handymax tankers, and Handysize bulk carriers during the period from 2020 to mid-2023. Hypothesis testing is first conducted to test differences in ship prices depending on their CII ratings, and hedonic price regression models are subsequently used in different specifications to examine the effect of energy efficiency indices, age, size and timecharter rates on ship prices.

3. Methodology

3.1 Two sample *t*-test

A two-sample *t*-test is first conducted in the analysis to test whether second-hand ship prices for ships with a CII rating between A and C are different compared to second-hand ship prices for ships with a CII rating of D or E. The CII can be considered as a quality attribute of a ship here, similar to ship-specific characteristics that Tamvakis (1995) uses in his *t*-test analysis to compare different classes of ships with different characteristics[1]. The CII entered into force on January 2023, with ratings given in 2024 for the first year of its implementation (IMO 2024b). The CII is an operational measure of the carbon intensity of a ship, which calculates the total greenhouse gas emissions (GHG) generated over a year, linked with the cargo carried and distance travelled over that year. A carbon intensity between A and C is acceptable, with A being a 'major superior', whereas a rating of E (inferior) or a rating of D (minor inferior) for three consecutive years requires a shipowner or an operator to take measures to achieve at least a rating of C or above the following year (IMO 2024b).

A series of pairs of samples are created for the three ship types/sizes considered in this study, namely, Aframax tankers of a cargo capacity between 93,000 and 123,000 deadweight tonnes (dwt)[2], Handymax tankers of a dwt capacity between 32,200 and 53,800, and Handysize bulk carriers of cargo capacity between 20,200 and 43,500 dwt. The samples of each ship type/size are split into two categories, i.e. CII A-C and CII D-E, respectively. The null and alternative hypotheses are then defined as follows:

The null hypothesis is that there is no difference in ship prices in the second-hand market between ships rated under the A-C levels and ships rated under the D-E levels:

$$H_0: \mu_1 - \mu_2 = 0$$

The alternative hypothesis is that there is a difference in ship prices in the second-hand market between ships rated under the A-C levels and ships rated under the D-E levels:

$$H_1: \mu_1 - \mu_2 > 0$$

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[1] The focus here is on the CII, given its importance on ship performance, which can have a significant impact on vessels' values, financing, and chartering alternatives.

[2] The weight carried, measured in metric tonnes. It includes cargo, fuel, lubricating oil , water ballast, stores, fresh water, crew and effects, and baggage and passengers.

It is assumed that variances of the sub-samples are different. The means and variances are then used to calculate the t-statistic:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{1}$$

3.2 Hedonic price model of ship values

A hedonic price model is used which includes major factors identified in the literature as vessel values' attributes, as well as the two main energy efficiency variables of our study, that is, the EEXI and AER (the carbon intensity ratio based on which CII is determined) indicators:

$$lnPrice_{it} = \beta_0 + \beta_1 * lnTC\ Rate_{it} + \beta_2 * lnAER_{it} + \beta_3 * lnEEXI_{\iota\tau} + Age_{it} + \frac{Age_{it}^2}{100} + Size_{it} + \frac{Size_{it}^2}{100} + \varepsilon_{it} \tag{2}$$

According to this model, the $Price$ of transaction i at a given point in time t is a function of the one-year timecharter rate, $TC\ Rate$, of the respective ship type, the Age and $Size$ of a ship, the Attained Efficiency Ratio, AER, the Energy Efficiency Existing Ship Index, $EEXI$, and the random error term, ε_{it}.

The Ordinary Least Squares (OLS) regression comprises six models, where $TC\ Rate$ is used first, and then together with Age. The third model includes $TC\ Rate$, Age, and $Size$. The variable AER is introduced in the fourth model, and the variable $EEXI$ in the fifth model. Finally, all variables are included in the sixth model. The relationships between all variables are initially examined by performing pairwise correlation analysis for the three ship sizes/types chosen for this study.

The linear model is of the log-log function. The logarithmic transformation is used to conform with the normality and the homoscedasticity assumptions, since the residuals for each fitted model were skewed before the transformation and exhibited patterns of asymmetry. As in Adland et al. (2018), a second order term (scaled) is included for each of the variables Age and $Size$, to consider non-linear relationships (Albertijn et al. 2016). This choice introduces structural multicollinearity in the model, which is corrected after 'centering' the two variables and their respective squared terms[3].

3.3 Data description

The microeconomic analysis considers sales transactions occurred between 2020 and mid-2023, focusing on ship types and sizes for which a high number of sales were recorded during that period. The data provided by VesselsValue include the following characteristics for each ship type/size: the date the sale occurred, vessel name before and after the transaction, IMO number, age in years, size in dwt, the estimated value of the ship one day before the concluded sale by VesselsValue and the actual sale price in US$ millions. As regards energy efficiency variables, these include for every ship: the CII rating (taking a rate from A to E), the attained Annual Efficiency Ratio (AER) in grams of carbon dioxide (CO_2) per tonne-mile, and the EEXI in grams of CO_2 per dwt-mile. Moreover, the one-year timecharter rates corresponding to each shipping sub-sector in the sample are also included in the dataset.

The initial dataset includes 2,898 transactions between 1 January 2020 and 10 July 2023. More specifically, data for Aframax tankers include transactions from 1 January 2020 to 29 June 2023, data for Handymax tankers include transactions from 9 January 2020 to 10 July 2023, and data for Handysize dry bulk carriers include transactions from 3 January 2020 to 30 June 2023. The final sample includes 1,474 observations after removing those with incomplete data on sold prices or other ship characteristics. Tables 1a to 1c present summary statistics for the variables used in the analysis across all ship types and sizes.

Table 1a. Descriptive statistics for Aframax tankers.

	No of obs.	Mean	Std. Dev.	Min	Max
Second-hand Price (US$ million)	309	27	15	8	112
Age (years)	309	15	5	0	25
Size (dwt)	309	109,874	4,425	93,000	123,000
AER (g CO2/t-nm)	309	4.36	1.21	2.50	19.59
EEXI (g CO2/dwt-nm)	309	3.54	0.37	2.15	4.64

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[3] 'Centering' involves the subtraction of the mean from each value of the dependent variable(s) for which higher order terms are used. The Variance Inflation Factors (VIF) used to detect multicollinearity resulted in values of around 1 to 2 in most of the cases across all models.

Table 1b. Descriptive statistics for Handymax tankers.

	No of obs.	Mean	Std. Dev.	Min	Max
Second-hand Price (US$ million)	516	17	8	4	50
Age (years)	516	15	5	0	26
Size (dwt)	516	45,911	5,361	32,200	53,800
AER (g CO2/t-nm)	516	7.76	16.57	0.71	378
EEXI (g CO2/dwt-nm)	516	5.62	0.72	3.97	7.93

Table 1c. Descriptive statistics for Handysize dry bulk carriers.

	No of obs.	Mean	Std. Dev.	Min	Max
Second-hand Price (US$ million)	649	13	6	1	34
Age (years)	649	13	5	1	33
Size (dwt)	649	33,207	4,212	20,200	43,500
AER (g CO2/t-nm)	649	7.92	2.28	4.59	54.82
EEXI (g CO2/dwt-nm)	649	6.41	0.76	4.43	8.97

The average second-hand price of Aframax tankers is the highest, whereas that of a Handysize bulker is the lowest, with the price of a larger ship size demonstrating higher volatility as indicated by the standard deviation. All ship types in the sample are 15 years old on average with the same standard deviation. The smaller the ship size, the higher both the AER and the EEXI indices on average. This can be expected since the larger the ship size, the lower the emissions generated per amount of transport work. Moreover, the AER being an operational indicator, varies significantly more than the EEXI regardless of the ship type/size, reflecting the changing pattern with which a ship is operated at a certain period of time, especially with respect to operating speeds and distances sailed.

Table 2a. Aframax tanker characteristics per CII rating.

CII Rating	No of obs.	Second-hand Price (US$ million)	Age (years)	AER (g CO2/t-nm)	EEXI (g CO2/dwt-nm)
CII A	42	44	6	3.15	3.10
CII B	53	27	15	3.84	3.52
CII C	141	25	17	4.30	3.61
CII D	55	19	19	4.95	3.64
CII E	18	25	16	7.36	3.67

Table 2b. Handymax tanker characteristics per CII rating.

CII Rating	No of obs.	Second-hand Price (US$ million)	Age (years)	AER (g CO2/t-nm)	EEXI (g CO2/dwt-nm)
CII A	103	28	8	5.19	4.99
CII B	168	16	15	6.32	5.75
CII C	177	14	17	7.42	5.74
CII D	46	13	18	9.06	5.94
CII E	22	10	19	30.74	5.91

Table 2c. Handysize dry bulk carrier characteristics per CII rating.

CII Rating	No of obs.	Second-hand Price (US$ million)	Age (years)	AER (g CO2/t-nm)	EEXI (g CO2/dwt-nm)
CII A	15	19	8	5.58	5.62
CII B	62	17	10	6.39	5.91
CII C	209	14	12	7.26	6.27
CII D	223	12	14	8.01	6.52
CII E	140	11	15	9.72	6.73

Tables 2a to 2c present a breakdown of values, age, AER and EEXI, according to the specific CII rating across all ship types. The higher the CII rating, the higher the value of a ship in the second-hand market and the lower the age of a ship. The only exception in the sample is the Aframax tanker category rated at CII E, where the average age is lower than at category CII D and with a higher second-hand value than category CII D. It should be noted that this could be due to the low number of CII E category observations in the sample compared to the rest rating categories. Further, the lower the CII rating, the higher both the AER and EEXI indicators across all ship types, which is expected as these variables are correlated with each other.

4. Empirical results

4.1 Results from two sample *t*-tests

A two sample *t*-test analysis is first conducted, assuming unequal variances, to test whether there are any differences in vessel valuation in the second-hand market between vessels rated with a CII A-C and those rated with a CII D-E. Table 3 reports the results across all ship types, including the mean, critical t values, p-value, number of observations and degrees of freedom.

Table 3. Two sample *t*-test results.

	Aframax tanker		Handymax Tanker		Handysize dry bulk carrier	
	CII A-C	CII D-E	CII A-C	CII D-E	CII A-C	CII D-E
Mean	29	21	18	12	15	12
No of obs.	236	73	448	68	286	363
T Critical (one tail)	1.66		1.66		1.65	
P(T<=t) one-tail	0.000		0.000		0.000	
df*	116		125		511	

Notes: the null hypothesis is that there is no difference between the mean of CII A-C and the mean of CII D-E; the alternative hypothesis is that the difference between the means is greater than zero i.e. a one-tailed test.*df: degrees of freedom

The null hypothesis is rejected in all cases, in other words there is significant difference between the second-hand prices of ships rated A-C and those rated D-E in our samples. The results for Aframax tankers (t (116) = 4.21, p = 0.000), Handymax tankers (t (125) = 8.28, p = 0.000), and Handysize bulk carriers (t (511) = 6.19, p = 0.000), give a t-statistic greater than the critical value in each case, and therefore there is sufficient evidence that higher CII-rated ships are rewarded in the second-hand market across all ship categories.

4.2 Correlation analysis

Correlations between all variables included in the hedonic regressions are presented in Tables 4a to 4c across all ship types[4]. First, it can be seen that there is a very strong negative correlation between the second-hand price and age across all ship categories, with correlation coefficients ranging from -0.71 to -0.83, indicating that age is a very important determinant of second-hand ship values. Second, there is a moderate (0.30 for Handymax tankers) to strong (0.40 for Aframax tankers, 0.49 for Handysize bulkers) positive correlation between timecharter rates

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[4] Pearson product-moment correlation coefficients measure linear relationships between variables, and therefore they do not detect any non-linear relationships.

and ship values since the freight and timecharter markets drive ship values. Third, size and values are also positively correlated, since the larger the ship size within a ship category, the more expensive its price, with coefficients ranging from 0.34 for Aframax to 0.41 and 0.65 for Handymax tankers and Handysize bulkers, respectively.

Table 4a. Correlation analysis for Aframax tankers.

	Size	Age	AER	Second-hand Price	Timecharter Rate	EEXI
Size	1					
Age	-0.31	1				
AER	-0.23	0.33	1			
Second-hand Price	0.34	-0.79	-0.31	1		
Timecharter Rate	-0.03	0.07	-0.02	0.40	1	
EEXI	-0.43	0.50	0.32	-0.48	0.05	1

Table 4b. Correlation analysis for Handymax tankers.

	Size	Age	AER	Second-hand Price	Timecharter Rate	EEXI
Size	1					
Age	-0.30	1				
AER	-0.17	0.15	1			
Second-hand Price	0.41	-0.83	-0.13	1		
Timecharter Rate	-0.05	0.13	0.05	0.30	1	
EEXI	-0.51	0.43	0.12	-0.49	0.06	1

Table 4c. Correlation analysis for Handysize bulk carriers.

	Size	Age	AER	Second-hand Price	Timecharter Rate	EEXI
Size	1					
Age	-0.65	1				
AER	-0.41	0.47	1			
Second-hand Price	0.65	-0.71	-0.39	1		
Timecharter Rate	0.03	-0.03	-0.02	0.49	1	
EEXI	-0.79	0.60	0.38	-0.65	-0.04	1

When it comes to energy efficiency indicators, both AER and EEXI are found to be negatively correlated with second-hand prices. The EEXI shows a higher coefficient than AER across all ship categories, whilst the strength of the relationship between values and EEXI is moderate (-0.48 and -0.49 for tankers) to strong (-0.65 for Handymax bulkers). The coefficients between second-hand prices and AER range from -0.13 for Handymax tankers to -0.31 for Aframax tankers and -0.39 for Handysize bulkers. The AER and EEXI are also positively correlated with each other since they both measure energy efficiency of ships.

Other notable relationships are those between size, age and energy efficiency indicators. The larger the ship size, the lower the AER and EEXI across all ship categories, with coefficients ranging from -0.17 to a -0.79, and the EEXI having a stronger negative coefficient than AER regardless of the ship category. The explanation of the negative correlation is due to economies of scale, since a given quantity of fuel consumed and therefore of emissions generated is spread over a larger cargo capacity, all else being equal.

Similar to size, age is positively correlated with both AER and EEXI, with the EEXI again found to have higher coefficients than AER across all ships. The coefficients show strong and very strong relationships between age and energy efficiency, since the older a ship is, the lower its energy efficiency becomes, all else being equal. Moreover, size and age are negatively correlated, indicating the deliveries of new ships with a gradually larger size throughout time. Finally, there are very weak – almost negligible – coefficients between timecharter rates and size, age, AER and EEXI across all ship categories, with the direction of the relationships to vary depending on the ship category.

4.3 Results from hedonic price models

The results from the hedonic price regressions for all ship categories are presented in Tables 5a to 5c. Six models are used to estimate the effect of ship-specific characteristics and market conditions on second-hand ship prices, including the operational and technical efficiency indicators. First, the effect of timecharter rates is tested in Model 1. The R-squared ranges from 0.13 for Aframax tankers to 0.30 for Handysize bulkers with an elasticity of about 0.60-0.80 on ship prices, meaning that for every 1% increase in the one-year timecharter rates, the second-hand ship price increases by 0.62% to 0.78%. Second, when the variable age is added in Model 2, the R-squared is increased significantly by 0.66 for Aframax tankers to 0.73 for Handymax tankers and 0.52 for Handysize bulkers, which shows that age is the most important explanatory variable of ship prices. Thus, a one unit increase of age reduces the value of a ship by 8.5% (Handymax tankers) to 7.3% (Handysize bulkers). The relationship between age and ship prices is negative, with the second-order terms resulting in negative coefficients for the tankers and a positive coefficient for Handysize bulkers. These relationships and signs are in line with the correlation coefficients found in the previous section.

Model 3 includes the timecharter rate, age and size variables. The relationship between price and size is positive as expected, given the higher earning potential of a larger ship, and the R-squared is further increased across all ship types, thus increasing the explanatory power of the model. As size increases by one unit, the ship price increases by 3.2% (Handysize bulkers) to 1.4% (Aframax tankers). The second-order term for size is found positive for Aframax tankers and Handysize bulkers but negative for Handymax tankers. The negative second-order for the latter means that that size increases lead to decreasing asset values. This could be attributed to 'standard' cargo quantities which do not utilise the maximum or near maximum cargo space of a tanker. Similarly, it could also be due to the relationship between the dwt capacity and the volume of various oil products and chemicals typically transported by this tanker type and size. More specifically, oil products of relatively low density require more space in the tanks but have lower weight compared to higher density petroleum products. It should be noted that results for Models 1 to 3 are highly significant for all ship categories at the 1% level[5].

The variable AER is introduced in Model 4, whilst EEXI is introduced in Model 5. Finally, all explanatory variables are included in Model 6. Both variables are negatively correlated with second-hand ship prices, with EEXI having a higher regression coefficient than AER in the case of Aframax and Handymax tankers. It should be noted that EEXI is found not statistically significant in the case of Handysize bulkers, with the R-squared increased only by adding AER in the model. Yet, the explanatory power increases little when introducing AER and EEXI in Models 4 to 6 for tankers. Coefficients for AER are high in the case of Aframax tankers and Handysize bulkers, whereas coefficients for EEXI are high for tankers only. A 1% increase in the value of EEXI reduces Aframax tanker prices by 0.40-0.46% and Handymax tankers by about 0.25%. A 1% increase in the AER reduces prices for Handysize bulkers by about 0.30% and 0.14-0.19% for Aframax tankers, depending on the model specification, and by 0.07% for Handymax tankers.

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[5] The exception is the second-order term for ship size in Model 3 of Handymax tankers.

Table 5a. Hedonic price regression models for Aframax tankers.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent variable: log of Price						
Log of AER				-0.187***		-0.141***
				(0.053)		(0.054)
Log of EEXI					-0.455***	-0.395***
					(0.101)	(0.103)
Log of 1-Year TC Rate	0.780***	0.868***	0.863***	0.861***	0.864***	0.862***
	(0.084)	(0.032)	(0.030)	(0.029)	(0.029)	(0.029)
Age at sale		-0.087***	-0.084***	-0.082***	-0.082***	-0.080***
		(0.003)	(0.002)	(0.003)	(0.002)	(0.002)
Age at sale squared/100		-0.146***	-0.151***	-0.156***	-0.171***	-0.172***
		(0.030)	(0.028)	(0.027)	(0.027)	(0.027)
Size			0.014***	0.013***	0.011***	0.010***
			(0.002)	(0.002)	(0.002)	(0.002)
Size squared/100			0.144***	0.152***	00143***	0.149***
			(0.038)	(0.037)	(0.037)	(0.037)
Intercept	-4.698***	-5.548***	-5.524***	-5.229***	-4.950***	-4.804***
	(0.843)	(0.325)	(0.300)	(0.307)	(0.318)	(0.320)
R^2	0.221	0.887	0.904	0.908	0.910	0.912
Number of observations	309	309	309	309	309	309

* Statistical significance at 10% level ** Statistical significance at 5% level *** Statistical significance at 1% level. Standard errors are reported in parentheses.

Table 5b. Hedonic price regression models for Handymax tankers.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent variable: log of Price						
Log of AER				-0.067**		-0.067**
				(0.031)		(0.031)
Log of EEXI					-0.250***	-0.250***
					(0.068)	(0.067)
Log of 1-Year TC Rate	0.623***	0.822***	0.843***	0.843***	0.842***	0.843***
	(0.073)	(0.030)	(0.026)	(0.026)	(0.026)	(0.026)
Age at sale		-0.089***	-0.082***	-0.080***	-0.080***	-0.078***
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Age at sale squared/100		-0.125***	-0.084***	-0.084***	-0.098***	-0.098***
		(0.025)	(0.021)	(0.021)	(0.021)	(0.021)
Size			0.016***	0.015***	0.013***	0.021***
			(0.002)	(0.002)	(0.002)	(0.002)
Size squared/100			-0.069**	-0.057*	-0.079**	-0.066**
			(0.031)	(0.031)	(0.031)	(0.031)
Intercept	-3.304***	-5.204***	-5.391***	-5.269***	-4.951***	-4.831***
	(0.705)	(0.291)	(0.250)	(0.256)	(0.275)	(0.279)
R^2	0.125	0.857	0.896	0.897	0.898	0.899
Number of observations	516	516	516	516	516	516

* Statistical significance at 10% level ** Statistical significance at 5% level *** Statistical significance at 1% level. Standard errors are reported in parentheses.

Table 5c. Hedonic price regression models for Handysize dry bulk carriers.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent variable: log of Price						
Log of AER				-0.297***		-0.302***
				(0.058)		(0.059)
Log of EEXI					-0.069	0.048
					(0.113)	(0.113)
Log of 1-Year TC Rate	0.695***	0.638***	0.636***	0.639***	0.636***	0.639***
	(0.041)	(0.021)	(0.019)	(0.018)	(0.019)	(0.018)
Age at sale		-0.076***	-0.057***	-0.052***	-0.056***	-0.053***
		(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
Age at sale squared/100		0.086***	0.021	0.010	0.015	0.013
		(0.021)	(0.022)	(0.022)	(0.024)	(0.023)
Size			0.032***	0.027***	0.030***	0.028***
			(0.003)	(0.003)	(0.003)	(0.003)
Size squared/100			0.120***	0.111***	0.118***	0.112***
			(0.041)	(0.040)	(0.041)	(0.040)
Intercept	-4.229***	-3.704***	-3.694***	-3.102***	-3.564***	-3.182***
	(0.398)	(0.200)	(0.180)	(0.210)	(0.277)	(0.282)
R^2	0.304	0.826	0.860	0.865	0.860	0.865
Number of observations	649	649	649	649	649	649

* Statistical significance at 10% level ** Statistical significance at 5% level *** Statistical significance at 1% level. Standard errors are reported in parentheses.

5. Discussion and conclusions

The introduction of EEXI and CII indicators by the IMO is expected to affect ship values in the second-hand markets at the technical, design and operational levels. Not only will these measures have implications for the energy efficiency, but also on values, chartering policies, financing, operation and trading of ships. The results of this paper contribute to the literature by examining the effect of the two newly implemented efficiency measures of CII and EEXI on ship values. Although there are studies which investigate the impact of fuel and energy efficiency on ship values in the literature (Adland et al. 2018; Adland et al. 2023), they do so at the nominal level. This paper is the first to consider not only the technical (EEXI), but also the operational level (CII and AER). Moreover, the consideration of these two measures is important from both policy and practice perspectives, since these are the two formal indicators that the industry will use from 2024 onwards to evaluate the energy efficiency of ships. The findings of this study could be used by policy makers to inform their decision making on environmental regulations and industry stakeholders to inform their decisions on investments, operations and chartering policies.

The results are in line with economic theory and findings from other studies in the literature. Timecharter rates are positively related with ship prices and are significant factors of values since they determine the earnings potential of a ship. Age has a significant and negative relationship with ship values reflecting the depreciation of a ship as it gets older, and therefore the gradually lower earnings potential. Ship size is positively related with values, meaning that a larger cargo capacity increases the earnings potential of a ship. However, there are also non-linear relationships between age, size and ship prices in either direction. When it comes to AER and EEXI, they are both significant explanatory variables for almost all ship categories and have a negative relationship with ship values. The EEXI has a higher elasticity than AER in all model specifications for tankers but is found not significant in the case of Handysize bulk carriers. This could mean that at this initial period of the implementation of these measures, the industry values more the energy efficiency determined at the technical level of a ship than the way it is operated. It should be noted that the sample includes data up to mid-year of 2023, and therefore more data are needed to fully assess the impact of CII and AER on asset values.

The results suggest that age is the most important determinant for ship values followed by timecharter rates and ship size, which are line with findings from other studies which used different model specifications (Adland and Köhn 2019; Adland et al. 2018; Adland et al. 2023). Moreover, the results and coefficients are also in line with Adland et al. 2018 and Adland et al. 2023 when it comes to energy efficiency related variables, although it should be noted that the samples differ with respect to the period of coverage. The choice of a parametric model which considers non-linear relationships as in Adland et al. (2018) allows a comparison of results for the second-order variables as well. The second-order term of age for Handysize bulkers is found positive as in Adland et al. (2018) who also used the same ship type in their study. Yet, the second-order terms of age for tankers are found negative in this study. On the other hand, the second-order term for size is found positive for Handysize bulkers, in contrast to Adland et al. (2018), which may be attributed to differences in sample size and period of coverage. It is only found negative for Handymax tankers in this study, which can be explained due to lower dwt utilisation of these tankers, depending on the stowage factor of various oil products.

This paper considers the main variables affecting ship values identified in the literature along with the EEXI and AER, but certain ship-specific variables are not included in the models since they were not provided in the dataset. More specifically, technical specifications of vessels such as engine type and relevant qualities, speed, build country and various other equipment-related specifications are not included here as in other studies in the literature. Future research could examine the impact of CII, AER and EEXI on ship values by including those variables along with alternative propulsion, fuel type and type and number of energy saving devices. Moreover, the time period in the dataset could be split on an annual basis or in the period before and after implementation or by including relevant interaction terms in the models also considering interactions between market factors and ship-specific variables. Finally, this study considered only certain types and sizes of ships. Future research could examine the impact of energy efficiency measures on second-hand ship prices of other sectors.

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