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SECOND-HAND PRICE VOLATILITY OF GREEN SHIPS: AN EMPIRICAL ANALYSIS ACROSS MAIN SHIPPING SEGMENTS

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Diskussionspapier Nr. 182
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Second-hand price volatility of green ships: an empirical analysis across main shipping segments

Harm Hauke Ross

Zusammenfassung / Abstract

This work analyzes economic implications of climate change regulation in maritime transport by providing an in-depth evaluation of the relationship between the green profile of ships and their second-hand price volatility. It takes into account findings from an analysis of 500 ships across main shipping segments. Statistical results based on the Energy Efficiency Design Index (EEDI) and the standard deviation of year-to-year changes in second-hand ship prices indicate that, on average, green ships exhibit lower second-hand price volatility. Consequently green ships could provide more stable collateral to financiers and potentially steadier economic prospects to ship owners. In addition, this paper introduces the concept of stochastic dominance when analyzing the utilization prospects in the context of the chartering decision-making process of ships with different environmental profiles. It therefore complements existing research on split incentives as a barrier to energy efficiency.

Schlagworte / Keywords: energy efficiency design Index, ship price volatility, stochastic dominance, maritime transportation, air emissions from ships, MARPOL Annex IV

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) treaty (United Nations, 1992) together with its extension under the Kyoto Protocol (United Nations, 1998) addressed the need for reducing CO_2 emissions to prevent climate change. According to estimates by the third greenhouse gas study (3rd GHG study) of the International Maritime Organization (IMO) (Smith et al., 2014), in the period between 2007 and 2012, 3.1% of global CO_2 emissions came from the shipping industry; 2.6% alone from ocean transport. The 3rd IMO GHG study forecasts that emissions will increase by about 50-250% by 2050 from 2012 levels if no action is taken.

In response, the IMO has sought to prompt the decarbonization of the maritime industry by amending Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) (IMO, 2011). The amendment, which took effect in January 2013, is the first regulation covering the energy efficiency of ships. It introduced the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) to reduce CO_2 emissions from the maritime industry over time. However, despite the existing standards introduced by the EEDI regulations, the industry`s share of global CO_2 emissions could still increase to approximately 17% (Cames et al., 2015). Therefore, policy-making efforts continued. In 2018, the IMO adopted the Initial IMO Strategy on reduction of GHG emissions from ships (Initial IMO Strategy) in resolution MEPC.304(72) and introduced the target of reducing GHG emissions by at least 50% of the 2008 level by 2050. The IMO`s vision is to phase them out completely within this century (IMO, 2018). In order to comply with EEDI standards, the adoption of emission-reduction technologies from new ships (Bouman et al., 2017) or the retrofitting of existing ships (Stulgis, 2014) is required. Following Schinas et al. (2018), a 'green ship' in the context of this work is defined as a ship that is, in contrast to a conventional ship, equipped with innovative green technology in order to improve its environmental footprint. Regardless of the selected technology, significant upfront investment is required to meet EEDI standards (Bazari and Longva, 2011) and the purchase price of greener ships is expected to be higher than that for conventional ships (DNV GL, 2014).

Access to capital for the maritime industry is constrained as several banks have reduced their ship finance activities since the global financial crisis in 2008, resulting in financial barriers for investments in more environmentally friendly technologies (Wang et al., 2010; Maddox Consulting, 2012; Rehmatulla and Smith, 2015a). Therefore, recent research efforts have focused on alternative financing models for green ships. Schinas and Metzger (2019), for example, introduced pay-as-you save models, Schinas et al. (2018) analyzed the use of export credit schemes for financing green ships and Stulgis et al. (2014) presented third-party financing models. Since a ship could serve as a collateral for its financing loan and the asset could be liquidated in a default scenario (Benmelech and Bergmann, 2008), assessing the second-hand value of ships is important for financiers. In addition to financiers, the link between the green profile of ships and their second-hand prices is relevant for ship owners alike. Ship owners` position towards energy efficient investments could be determined by the ownership trend in shipping (Lonsdale et al., 2019). Stott (2014) shows that less than 20% of ship owners operate ships over their specified working life. Across drybulk, tanker and containerships, in case of several owners, the ownership duration reduces from on average approximately 10.5 years to on average around 3.5 years. These segments represent a combined total share of the world fleet in terms of dead weight tons (DWT) of approximately 84.7% (UNCTAD, 2017), thus emphasizing the important role of the second-hand ship market in the context of achieving emission reductions in maritime transport. In terms of energy efficiency, there is inconclusive evidence as to whether energy efficient improvements are reflected in valuations of second-hand ship prices (Lonsdale et al., 2019). In fact, the uncertainty about the second-hand value of greener ships has been identified as a barrier to their implementation (Faber et al., 2015). Ross and Schinas (2019) conclude that higher stated energy performance is on average displayed more often by ships of higher commercial value and that further research on the impact of energy performance on economic factors such as ship prices would be beneficial.

In summary, the need for energy efficiency investments in shipping increases in light of rising global regulation and capital available to the industry is experiencing being constrained. On that account, it is crucial to analyze the relationship between the green profile of a ship and its second-hand prices over time. This paper presents the empirical analysis of a sample of 500 ships across main shipping segments, which is considered to be its key contribution to research in the field of maritime transport.

The paper is structured as follows: Section 2 provides a literature review and explains the selection of criteria for the analysis. Section 3 describes the dataset and methodology. Section 4 presents and discusses the results of the analysis. Section 5 summarizes the findings and concludes this work.

2. Literature Review and Criteria Selection

2.1 The Energy Efficiency Design Index

The development of the EEDI goes back to two studies on greenhouse gas emissions from ships that were carried out on behalf of the IMO in 2000 and 2009 (Buhaug et al., 2009; Skjølsvik et al., 2000). A number of additional studies on GHG emissions in maritime industries were published around the time of the second IMO GHG study, for example Kollamthodi et al. (2008), Harrould-Kolieb (2008), DeltamarinLtd (2009) and Faber et al. (2009), emphasizing the increasing awareness of both policy-makers and industry for environmental challenges over time. The EEDI provides an evaluation of a ship`s energy efficiency based on CO_2 emissions in gram per unit of transport expressed in ton-miles. The adoption of the EEDI was based on the IMO resolution MEPC.203(62) (IMO, 2011) and guidelines for development of SEEMP were introduced based on the IMO resolution MEPC.213(63) (IMO, 2012a). The ship-specific EEDI value is calculated using a formula provided in the IMO Resolution MEPC.245(66) (IMO, 2014). A simplified version of this formula is shown in Equation 1 below:

Equation 1: The simplified EEDI formula

$$EEDI = \frac{CO_2\ from\ the\ propulsion\ +\ CO_2\ from\ the\ auxiliary\ -\ CO_2\ innovative\ technology}{DWT\ x\ speed}$$

The simplified EEDI formula emphasizes that energy efficiency can be increased either by increasing the denominator through higher utilization or speed adjustment of the ship or by decreasing the numerator through the reduction of CO_2 emissions or the use of more energy efficient technology (Schinas and Butler, 2016). The EEDI value of a specific ship type and size segment should be below the relevant reference line value in accordance with Resolution MEPC.215(63) (IMO, 2012b), otherwise measures need to be taken to reduce the value. Research in this context has for example looked at CO_2 reduction measures (Bouman et al., 2017; Eide et al., 2011; Eide et al., 2009) or ship design (Chen et al., 2011; Veenstra and Ludema, 2006). Going beyond certain emission reduction targets would require the implementation of step-change technologies such as use of biofuels and synthetic fuels (Rehmatulla et al., 2017). Reference line values will be tightened by the IMO over time, thereby stimulating continued technological development and forcing operators to increase the unit energy efficiency. Reduction factors for reference line values have been set for the period up to 2025 when the maximum reduction of 30% will become effective (IMO, 2011; Bazari and Longva, 2011).

While the EEDI does not account for other maritime emissions such as sulphur (IMO, 2008), it plays an important role in the Initial IMO Strategy to achieve the targeted GHG emission reductions (IMO, 2018). The IMO recently approved amendments to strengthen the existing mandatory requirements for energy efficiency of ships in MEPC 74 session. For example, the entry into effect date of EEDI phase 3 will be brought forward from 2025 to 2022 for several ship types (IMO, 2019). Using EEDI for academic analyses is a well-tested concept in academics, for example to analyze the status quo of industry`s energy efficiency (Ross and Schinas, 2019), the impact of energy efficiency on time charter rates (Agnolucci et al., 2014) or the development of ship-specific correction factors (Alisafaki and Papanikolaou, 2015). In conclusion, the EEDI is considered to be a suitable indicator for a ship`s green profile in the context of this analysis.

2.2 Second-hand Ship Prices

A large body of research into the estimation of ship prices is available in the literature. Publications from the early 1990s onwards focused on testing Fama's Efficient Market Hypothesis (Fama, 1965) including those by Veenstra and Franses (1995), Kavussanos and Alizadeh (2002), Adland and Koekebakker (2004), and Sodal et.al. (2006). According to Pruyn et al. (2011), the latest second-hand price models focus on micro-economic valuations, which consider vessel-specific factors such as hull type, age, speed, and DWT. Examples include the supply and demand function oriented model by Tsolakis (2005), the non-parametric multivariate density estimation by Adland and Koekebakker (2007), the generalized additive model by Köhn (2008) and the long-term asset value method ("LTAV") discussed by Mayr (2015). Stopford (2009) argues that there are four main factors driving second-hand prices for ships, namely freight rates, age, inflation, and expectations. In summary, trading activity and volume have been commonly found to affect ship prices, however, across different studies, new ship prices and freight rates have been confirmed as the most significant drivers of second-hand ship prices (Jiang and Lauridsen, 2012; Lun and Quaddus, 2009; Syriopoulos and Roumpis, 2006; Tsolakis et al., 2003). The following sub-sections introduce valuation concepts for second-hand ship prices as well as the aspect of second-hand ship price volatility.

2.2.1 Valuation of Second-hand Ship Prices

Due to the complexity of estimating second-hand ship prices, it is common practice for industry to outsource the valuation task to specialized third party valuers. A ship's market value is typically calculated by averaging the valuations of two well-established and reputable valuers (Gavalas and Syriopoulos, 2014). One of the established valuation methods utilizes the recent sale price of comparable ships. Potential drawbacks are time differences between transactions or different vessel specifications (Baltic Exchange, 2013). As ship price volatility reached record high levels following the global financial crisis in 2008, valuation methods shifted towards approaches based on earnings estimates, such as the LTAV method, which makes use of discounted cash flow analysis (Schinas and Kewitsch, 2015). The LTAV is calculated by discounting the expected free cash flow (FCF) with the weighted average cost of capital ($WACC$) (Mayr, 2015) as shown in Equation 2 below:

Equation 2: The LTAV

$$LTAV = \sum_{t=1}^{T} \frac{FCF_t}{(1 + WACC)^t}$$

2.2.2 Second-hand Ship Price Volatility

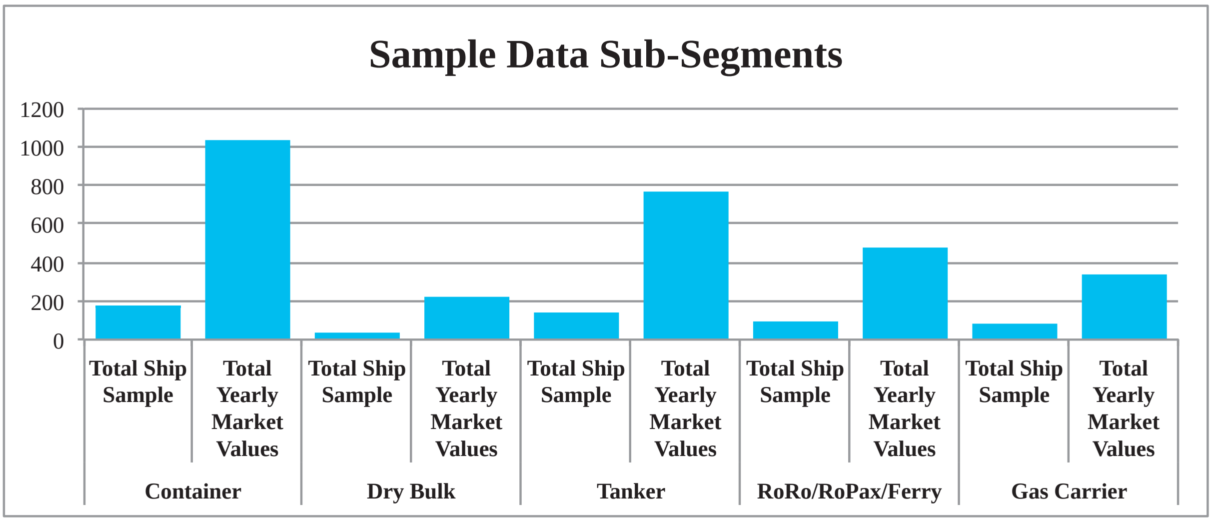
Ships are capital-intense assets, with profits and ship prices being greatly affected by high volatility (Greenwood and Hanson, 2013; Lun et al., 2006). Research into the volatility of both ship prices and freight rates has attracted increased interest over the past 20 years. Kavussanos (1996a/b) first used Auto Regressive Conditional Heteroskedasticity models to show that freight rates and second-hand ship prices are time-variant and paved the way for further research including Kavussanos and Nomikos (2000), Tvedt (2003), Kavussanos and Visvikis (2004), Lu et al. (2008) and Drobetz et al. (2012). According to the classification of risks provided by Dhaene et al. (2003), volatility is considered to be an overall risk as it contains the entire set of outcomes as opposed to a downside risk such as value-at-risk, lower partial moments (Bawa, 1975) or the Omega function (Keating and Shadwick, 2002), which only consider the tails. The accurate analysis of volatility is important for making informed risk management decisions and has implications for various financial areas (Pyle, 1997). For instance, the theoretical asset pricing models of Sharpe (1964) and Black and Scholes (1973) directly relate the change in the price of the asset to its own variance, while Pindyck (1984) showed in an empirical study that the decline in stock prices during the 1970s could be attributed to volatility increase. Volatility does not measure the direction of price changes, merely their dispersion. This is because when calculating standard deviation, all differences are squared so that negative and positive differences are combined into one quantity. As a result, ships with higher second-hand price volatility are characterized by larger swings in their second-hand prices over a given period of time. In the context of volatility, outperformance risk is treated the same as underperformance risk. In conclusion, second-hand ship price volatility is deemed to be a suitable criterion in the context of this study in order to allow for an holistic analysis addressing different industry stakeholders including ship owners, policy-makers and financiers.

3. Data and Methodology

3.1 Data

A sample of 500 ships over 400GT was compiled providing a total of 2,840 yearly market values. The sample covers a diverse set of ships across different age classes (299 ships aged ≤ 10 years and 201 ships aged > 10 years) and shipping segments as summarized in Figure 1.

Figure 1: Summary of sample data



Ocean transport is a highly segmented industry (Kavussanos 2010, 2003, 1996 a/b; Tsouknidis, 2016). The sample contains examples of cargo-carrying ships, passenger ferries and RoPax vessels in order to allow for generalizing results and to draw cross-sectional conclusions. The sample represents around 0.53% of the 93,262 vessels in the global merchant ship fleet (UNCTAD, 2018). While the maximum time series of yearly market values per ship in the sample is 7 years, the average time series across shipping segments covers a period of approximately 5.7 years per ship, which is close to the 6-7 years period of a typical shipping cycle (Stopford, 2009).

3.2 Methodology

3.2.1 EEDI Grouping

For the purpose of this study, the differential ($\Delta EEDI$) is derived from Equation 3 below, where $EEDI_{ref}$ is the relevant reference line value and $EEDI_{estimated}$ is the ship`s estimated EEDI value. Following the Ross and Schinas` methodology (2019), this differential yields the green profile of the different ships in the sample. The expected environmental footprint in design terms is considered to be smaller, the larger the negative differential $\Delta EEDI$.

Equation 3: Calculating $\Delta EEDI$

$$\Delta EEDI = EEDI_{estimated} - EEDI_{ref}$$

The dataset was divided into two subsets: ships with a negative $\Delta EEDI$, which are considered to be more efficient than the reference line value (group A) and ships with a positive $\Delta EEDI$, which are considered to be less efficient than the reference line value (group B). In the context of this study, ships in group A are considered to be characterized by higher energy efficiency as per the EEDI standard than ships in group B. Since the EEDI aims to target the implementation of measures to reduce the shipping sector`s CO_2 emissions (Rehmatulla et al., 2017), ships in group A are considered to represent the area of green ships as per the definition provided in the Introduction section.

3.2.2 Calculating Ship-specific Second-hand Price Volatility

The relative year-to-year market value changes were calculated for each ship in accordance with Equation 4 to account for the variation in second-hand prices resulting from, for example, differences in ship size and technical specification.

Equation 4: Calculating relative year-to-year market value changes

$$\Delta MV_t = \frac{MV_t - MV_{t-1}}{MV_{t-1}}$$

Second-hand ship price volatility was calculated as the standard deviation of year-to-year changes in market value, $\sigma_{\Delta MV}$, of each ship over the available time period. $\sigma_{\Delta \mathrm{MV}}$ reflects the volatility of market values of each ship and homogenizes the sample based on a dimensionless measure. $\sigma_{\Delta \mathrm{MV}}$ has the same unit for all 500 vessels regardless of vessel size and USD market value.

In order to analyze the potential impact of energy efficiency on second-hand ship price volatility, the means of $\sigma_{\Delta MV}$ of groups A (negative $\Delta EEDI$) and B (positive $\Delta EEDI$) were compared and the results were tested for statistical significance, followed by a simple linear regression model.

3.3 Robustness Tests and Simple Linear Regression

It is of interest whether the difference in second-hand ship price volatility between more energy efficient and less energy efficient ships is of statistical significance. In order to determine the appropriate test statistics, a Shapiro-Wilk-test was performed to test for normal distribution of the datasets (Shapiro and Wilk, 1965) followed by an F-test to test if the variances of the two groups were equal (Snedecor and Cochran, 1989).

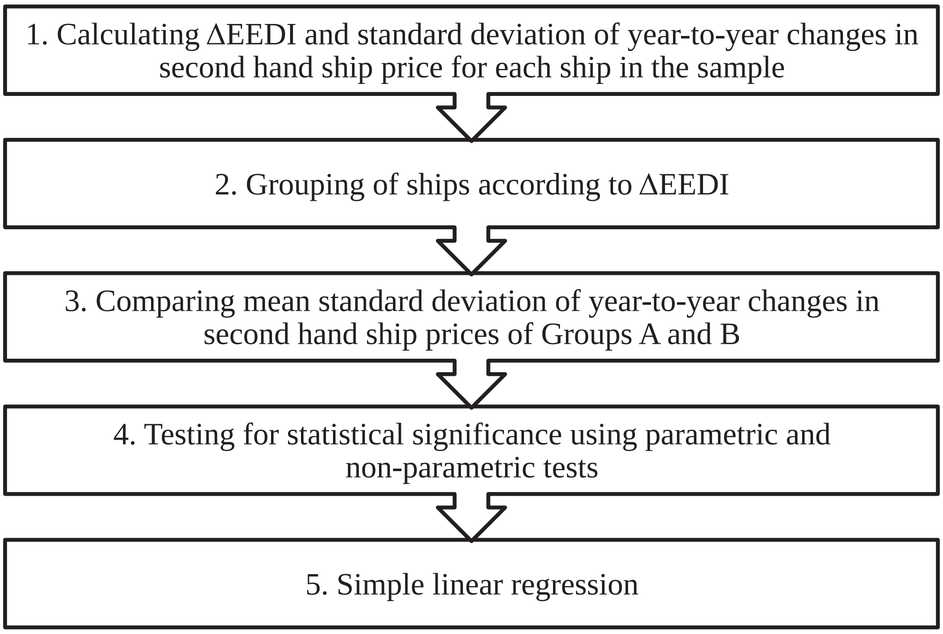
A simple linear regression was used to yield additional information on the relationship between the green profile and second-hand ship price volatility. Equation 5 shows a simple linear regression that models the relationship between $\sigma_{\Delta MV}$ as a dependent variable and $\Delta EEDI$ as an explanatory or independent variable:

Equation 5: Simple linear regression

$$\sigma_{\Delta MV_i} = \beta_1 + \beta_2 \; x \; \Delta EEDI_i \; + \; \varepsilon_i$$

where β_1 denotes the intercept, β_2 the regression coefficient and ε_i the error term. The methodological framework of the analysis is summarized in Figure 2 below:

Figure 2: Summary of Methodological Framework



4. Results and Discussion

4.1 Results

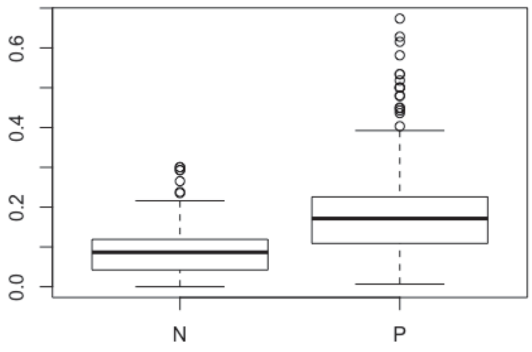
The descriptive statistics of the two EEDI groupings are summarized in Table 1 below.

Table 1: Descriptive statistics of EEDI groupings

Variable	N	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
σ Market Values	500	0	0.06879	0.12011	0.14368	0.18959	0.67364
σ Market Values negative ΔEEDI (Group A)	216	0	0.0422	0.08663	0.08899	0.11895	0.30036
σ Market Values positive ΔEEDI (Group B)	284	0.00668	0.10890	0.17137	0.18528	0.22531	0.67364

Table 1 shows that the means of the two groups are different. The mean $\sigma_{\Delta MV}$ for the group of more energy efficient ships (group A) is lower than that for the group of less energy efficient ships (group B) suggesting that, on average, the market values of group A ships exhibit lower volatility than group B ships. This is supported by a comparison of the box plot of the different groups, as shown in Figure 3, where N represents $\sigma_{\Delta MV}$ of group A with negative $\Delta EEDI$, and P represents $\sigma_{\Delta MV}$ of group B with positive $\Delta EEDI$.

Figure 3: Box plots



Results from the Shapiro-Wilk-test and the F-test indicate that the samples are not normally distributed (rejecting H_0 of normal distribution for group A with W=0.928 and p<0.01 as well as for group B with W=0.890 and p<0.01) and that variances are unequal (rejecting H_0 that true ratio of variances is equal to 1 with F=3.749, num df=283, denom df=215 and p<0.01), hence making the use of a non-parametric test more appropriate than a parametric test. In order to achieve more robust results, and given that the significant sample sizes of n=216 (group A) and n=284 (group B) justifies the assumption of normally distributed samples based on the central limit theorem (Fischer, 2011), a non-parametric test was performed before a parametric test. The Mann-Whitney U test was selected as it is best suited for two independent samples from populations violating the stringent assumptions of independent group`s t-test (Mann and Whitney, 1947). The t-test in the modified form of Welch`s t-test was selected as the parametric test based on Ruxton's (2006) findings that the Welch`s t-test shows more reliable results when testing two samples with unequal variances. Table 2 shows the results from both tests.

Table 2: Summary of parametric and non-parametric tests

Summary of parametric and non-parametric tests

Parametric test					**Non-parametric test**		
Welch`s t-test					Mann-Whitney U test		
t	df	Mean of Group A	Mean of Group B	p	U	Difference in location	p
11.982	444.38	0.08899	0.18528	<0.01	13092	-0.083	<0.01

The results of the Mann-Whitney U Test indicate that H_0*: true difference in* $\mu = 0$ should be rejected. Hence the difference in means of $\sigma_{\Delta MV}$ of group A and group B can be regarded as statistically significant. This result is supported by Welch`s t-test results, which indicate that mean $\sigma_{\Delta MV}$ is significantly higher for ships of lower energy efficiency (mean=0.18528) than ships of higher energy efficiency (mean=0.08899), t(444.38)=11.982, p<0.01. As a further robustness check, the same tests were computed with both a logarithmic and a square root transformation of the datasets and this indicated the same statistical significance of the findings. Table 3 shows the results from the simple linear regression.

Table 3: Simple linear regression results:

	Dependent variable:
	$\sigma_{\Delta MV}$
$\Delta EEDI$	0.280^{***}
	(0.024)
Constant	0.137^{***}
	(0.004)
Observations	500
R^2	0.217
Adjusted R^2	0.215
Residual Std. Error	0.095 (df = 498)
F Statistic	137.748^{***} (df = 1; 498)
Note:	*p<0.1; **p<0.05; ***p<0.01

The regression line for the data shown in Equation 6 has a positive slope, indicating that second-hand ship price volatility is higher when $\Delta EEDI$ is high.

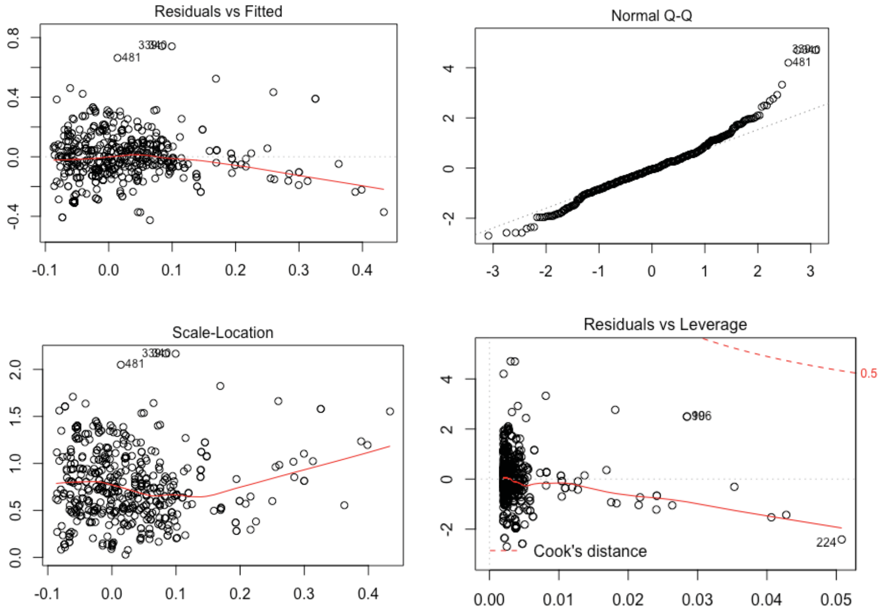
Equation 6: Regression Line

$$\sigma_{\Delta MV_i} = 0.137 + 0.28\ x\ \Delta EEDI_i\ +\ \varepsilon_i$$

From the adjusted R^2 value, it can be seen that approximately 21.5% of the variation in $\sigma_{\Delta MV}$ can be explained by ΔEEDI. The extent to which other factors play a role could be an area for further research. For example, a multiple regression analysis could be performed, which incorporates new ship prices and freight rates as additional covariates besides ΔEEDI. This could allow for an estimation of the contribution of ΔEEDI to $\sigma_{\Delta MV}$ after taking into account the main predictors as per the academic literature discussed in section 2.2.

The linear regression diagnostic plots are provided in Figure 4. The regression assumptions may be considered as met and the model seems to satisfactorily represent the data.

Figure 4: Simple linear regression diagnostic plots



4.2 Discussion

The findings of the empirical analysis show a statistically significant impact of energy efficiency as per the EEDI standard on second-hand ship price volatility. As summarized in section 2.2, literature highlights that new ship prices and freight rates are the most significant drivers of second- hand ship prices, giving rise to the question as to what extent energy efficiency impacts second-hand ship price volatility through these drivers. According to research in the maritime sector, one of the key barriers to increasing energy efficiency in shipping is the well-cited effect of split incentives (Rehmatulla and Smith, 2015a/b), i.e. operators have to bear the costs of implementing energy efficiency measures while the charterer enjoys the benefits in the form of lower fuel costs (Stulgis et al, 2014). Charterers only reward the fuel efficiency of a vessel with the payment of a charter rate premium to a limited extent, if at all (Agnolucci et al., 2014; Smith et al. 2013; Wang et al., 2010). In a conservative scenario, no benefits from higher energy efficiency on employment prospects, earnings or second-hand ship prices could be expected. At the same time, ship owners who operate their own vessels would be able to recoup their investment in energy efficiency through fuel cost savings (Faber et al., 2011). Considering, for example, that across major container shipping companies the ratio of owned vessels to chartered vessels was exemplarily around 35% - 55% in 2015 as shown by Ha and Seo (2017), the magnitude of the effect should not be underestimated.

For chartered ships, the concept of stochastic dominance provides an alternative perspective for the analysis of the employability criterion in order to evaluate the decision-making process in a conservative scenario where the charterer is not willing to pay a premium for a more energy efficient ship. In this case, it is assumed that the charterer would choose between two ships of similar dimensions and the same charter rate, but with one ship being more energy efficient than the other. Stochastic dominance criteria are decision making tools that aid the choice among different options in the absence of full information regarding the decision maker`s preferences. The concepts of First and Second Order Stochastic Dominance (FOSD and SOSD, respectively) have been extensively studied for risk averters (Bawa et al., 1985; Fishburn 1974, 1980) and risk seekers (Li and Wong, 1999; Stoyan 1983; Meyer, 1977), and developed in the area of finance and risk management (Kopa et al., 2018; Mosler and Scarsini, 1991; Whitmore and Findlay, 1978) as well as agriculture (Wilson et al., 2009; Harris and Mapp, 1986). One of the key principles underlying rational decision-making models is the idea that the decision maker should never choose an option that is statistically dominated by another option (Diedrich and Busemeyer, 1999). In classical utility theory, the idea of FOSD and SOSD is essentially related to the notion of maximizing a non-decreasing or concave von Neumann–Morgenstern utility function. In the context of this analysis, it is assumed that charterers are risk averters, which would translate into a concave von Neumann–Morgenstern utility function (McAfee and Lewis, 2009). Given that charterers across cargo-carrying segments such as dry bulk (Burns, 2012), containers (Clean Cargo Working Group, 2016) and tankers (Chia and Chia, 2014) are facing growing interest in their environmental footprint from external parties such as investors, industry associations and non-governmental organizations, there is an incentive for charterers to employ ships of lower environmental impact. It might thus be reasonably concluded that for the case of two vessels, A and B, if vessel A has a lower $\Delta EEDI$ and hence lower environmental impact than vessel B, then vessel A stochastically dominates vessel B, even in the stronger form of FOSD. A utility-maximizing charterer, who prefers more to less, would prefer vessel A than vessel B. Following the same argumentation, if vessel A dominates vessel B in the sense of SOSD, this is in line with the idea that a risk-averting charterer with an expected concave utility function would always prefer a more-efficient over a less-efficient vessel. Applying the standard literature definition in Equation 7 and Equation 8 below (Huang and Litzenberger, 1988) to the two vessel scenarios, vessel A first order stochastically dominates vessel B, if

Equation 7: FOSD

$F_A(z) \leq F_B(z) \;\; \forall z$, where $z \in S \subseteq \mathbb{R}$

Furthermore, vessel A second order stochastically dominates vessel B, if

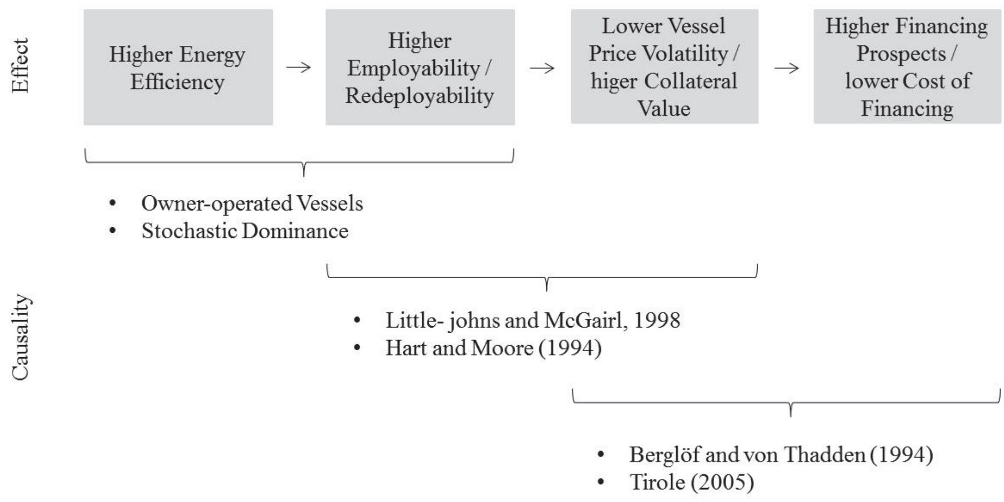
Equation 8: SOSD

$$\int_{-\infty}^{q} F_A(z)dz \leq \int_{-\infty}^{q} F_B(z)dz \quad \forall q$$

In reality, decision-makers often violate one of the axioms of the von Neumann–Morgenstern utility function; that being the independence of irrelevant alternatives (Ariely, 2009; Ariely and Wallsten, 1995). As Hubert et al. (1982) show, consumers usually have to choose between two alternatives whose attributes differ in several dimensions without one of the alternative being dominant in all dimensions. In this scenario, adding another dimension as a decoy, which is clearly dominated by only one of the two alternatives, can significantly influence the decision-making process (Ariely and Wallsten, 1995). This might lead to the result that consumers ignore certain dimensions and end up in a subjective dominance relationship. Momsen and Stoerk (2015) have used this concept in the area of energy policy in their research on renewable energy contracts. In the case of chartering decisions, the decoy could be an alternative that is dominated by higher energy efficiency in the form of a lower $\Delta EEDI$, thus being equal in the charter rate dimension but dominated in the energy efficiency dimension. Stulgis et al. (2014) argue that since charterers increasingly scrutinize the fuel bills of ships, the first ship owners who increase their ships` energy efficiency are expected to be rewarded with higher market competitiveness and an increased utilization of their ships. Furthermore, energy efficiency is deemed to increase the chances of winning charter contracts and provide for better utilization rates (Agnolucci et al., 2014). At the same time, pressure for existing ships to compete with more efficient new ships increases, resulting in uptake of retrofitting measures to allow existing ships remaining competitive (Rehmatulla et al., 2017). Therefore, the strong brand perception of energy efficiency is — all other dimensions *ceteris* *paribus* — expected to influence the chartering decision to the benefit of more efficient ships. Overall, the energy efficiency of a given vessel is considered to positively influence the earnings prospects and also the vessel`s second-hand price through better employability, even if the charterer would not be willing to reward higher efficiency with a premium on charterer rates.

Empirical research from the airline industry has shown that the ease of remarketing an aircraft is an important determinant of its expected collateral value (Littlejohns and McGairl, 1998). At the same time, debt tranches that are secured by more redeployable collateral are characterized by lower credit spreads and higher credit ratings, suggesting that the ability to pledge redeployable collateral lowers the cost of external financing (Benmelech and Bergmann 2009). In addition, Hart and Moore (1994) show that asset redeployability serves as better collateral for long-term debt. Similarly, Berglöf and von Thadden (1994) estimate that companies with fungible assets should be financed with long-term debt, while Tirole (2005) argues that more redeployable collateral helps to reduce the costs of external financing since assets can be sold for a higher price in an event of default. Figure 5 summarizes the causalities discussed here in combination with results from the empirical analysis.

Figure 5: Summary of discussion results



5. Conclusions

Climate change is a severe issue for the planet and collective actions between industry and regulators are needed to reduce the impact that industry has on the environment. In this paper, the relationship between the green profile of ships and second-hand ship price volatility is investigated in order to bridge the gap between environmental regulation and the economic effect of its implementation. The research presented here is therefore relevant for both industry stakeholders and policy-makers. Findings suggest that green ships with a higher energy efficiency as per the EEDI standard are likely to have better financing prospects as a result of their lower second-hand price volatility and thus more stable collateral values. While, as a typical limitation of statistical analysis, the magnitude of the effect, such as an adjusted R^2 of 21.5%, might not be accurate on a single ship basis, the direction of the effect is significant and indicates that higher energy efficiency yields higher collateral quality. As a potential explanation, the relevance of higher utilization is emphasized. It is shown that in a chartering decision-scenario between low and high-energy efficient ships, the higher energy efficient ones will likely stochastically dominate. This might result in higher utilization rates and steadier earnings prospects given the increasing environmental awareness of industry stakeholders. This could be of particular relevance with a view to new regulations on data collection and reporting. For instance, the EU`s Regulation on the Monitoring Reporting and Verification of shipping emissions (EU-MRV) (European Commission, 2019) will make data on operational emissions publicly available and will thus increase transparency between stakeholders. In deciding whether to opt for ships of higher or lower energy efficiency, this work indicates that a higher emphasis on energy efficiency benefits ship owners through potentially steadier economic prospects. The paper hence contributes a new perspective to the discussion on how to address barriers of energy efficiency in shipping. At the same time, the methodological framework presented in this study could potentially be applied to other industries such as the aviation or the electric vehicle market alike.

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