

Ross, Harm Hauke

**Working Paper**

## Second-hand price volatility of green ships: An empirical analysis across main shipping segments

Diskussionspapier, No. 182

**Provided in Cooperation with:**

Fächergruppe Volkswirtschaftslehre, Helmut-Schmidt-Universität (HSU)

*Suggested Citation:* Ross, Harm Hauke (2019) : Second-hand price volatility of green ships: An empirical analysis across main shipping segments, Diskussionspapier, No. 182, Helmut-Schmidt-Universität - Universität der Bundeswehr Hamburg, Fächergruppe Volkswirtschaftslehre, Hamburg

This Version is available at:

<https://hdl.handle.net/10419/226431>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

Diskussionspapierreihe  
Working Paper Series



HELMUT SCHMIDT  
UNIVERSITÄT  
Universität der Bundeswehr Hamburg

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

HARM HAUKE ROSS

Nr./ No. 182  
NOVEMBER 2019

Department of Economics  
Fächergruppe Volkswirtschaftslehre

Autoren / Authors

**Harm Hauke Ross**

Helmut-Schmidt-University Hamburg  
Department of Economics  
Holstenhofweg 85, 22043 Hamburg  
hh.ross@web.de

Redaktion / Editors

Helmut Schmidt Universität Hamburg / Helmut Schmidt University Hamburg  
Fächergruppe Volkswirtschaftslehre / Department of Economics

Eine elektronische Version des Diskussionspapiers ist auf folgender Internetseite zu finden / An electronic version of the paper may be downloaded from the homepage:

<https://www.hsu-hh.de/fgvwl/forschung>

Koordinator / Coordinator

Ralf Dewenter  
wp-vwl@hsu-hh.de

# **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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions from the maritime industry over time. However, despite the existing standards introduced by the EEDI regulations, the industry's share of global CO<sub>2</sub> 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<sub>2</sub> 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

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

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<sub>2</sub> 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<sub>2</sub> 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 subsections 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

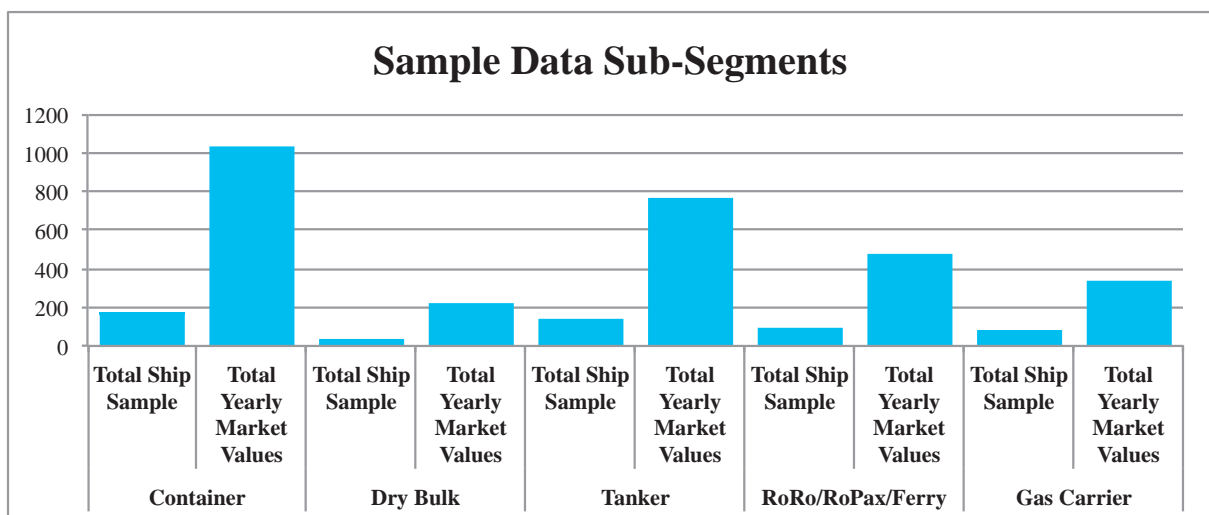
attributed to volatility increase. Volatility does not measure the direction of price changes, merely their dispersion. This is because when calculating standard deviation, all differences are squared so that negative and positive differences are combined into one quantity. As a result, ships with higher 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  $\leq 10$  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<sub>2</sub> 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.  $\sigma_{\Delta MV}$  reflects the volatility of market values of each ship and homogenizes the sample based on a dimensionless measure.  $\sigma_{\Delta MV}$  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).

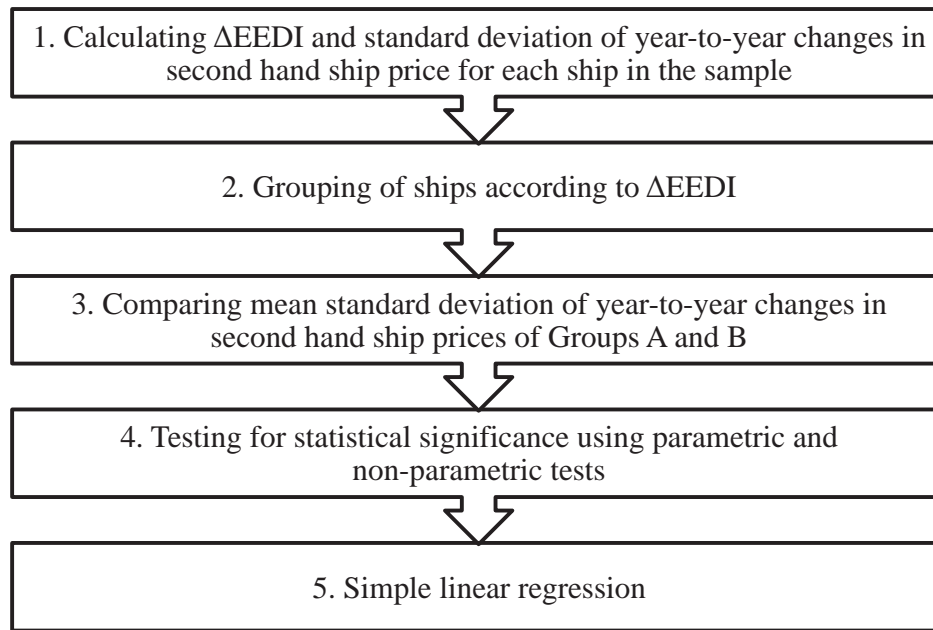
A simple linear regression was used to yield additional information on the relationship between the green profile and second-hand ship price volatility. Equation 5 shows a simple linear regression that models the relationship between  $\sigma_{\Delta MV}$  as a dependent variable and  $\Delta EEDI$ 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

Equation 5: Simple linear regression

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

where  $\beta_1$  denotes the intercept,  $\beta_2$  the regression coefficient and  $\varepsilon_i$  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

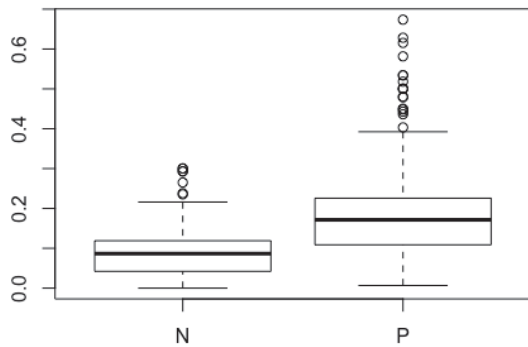
The descriptive statistics of the two EEDI groupings are summarized in Table 1 below.

Table 1: Descriptive statistics of EEDI groupings

| Variable   | N   | Minimum | 1st Quartile | Median  | Mean    | 3rd Quartile | Maximum |
|--|-----|---------|--------------|---------|---------|--------------|---------|
| $\sigma$ Market Values                                     | 500 | 0       | 0.06879      | 0.12011 | 0.14368 | 0.18959      | 0.67364 |
| $\sigma$ Market Values<br>negative $\Delta EEDI$ (Group A) | 216 | 0       | 0.0422       | 0.08663 | 0.08899 | 0.11895      | 0.30036 |
| $\sigma$ Market Values<br>positive $\Delta EEDI$ (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

| <u>Summary of parametric and non-parametric tests</u> |        |                 |                 |       |                            |                        |
|---|--------|-----------------|-----------------|-------|----------------------------|------------------------|
| <b>Parametric test</b>                                |        |                 |                 |       | <b>Non-parametric test</b> |                        |
| Welch's t-test  |        |                 |                 |       | Mann-Whitney U test        |                        |
| t   | df     | Mean of Group A | Mean of Group B | p     | U                          | Difference in location |
| 11.982  | 444.38 | 0.08899         | 0.18528         | <0.01 | 13092                      | -0.083                 |
|   |        |                 |                 |       |                            | p <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:

|                     | <i>Dependent variable:</i> |
|---------------------|----------------------------|
|                     | $\sigma_{\Delta MV}$       |
| $\Delta EEDI$       | 0.280***<br>(0.024)        |
| Constant            | 0.137***<br>(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

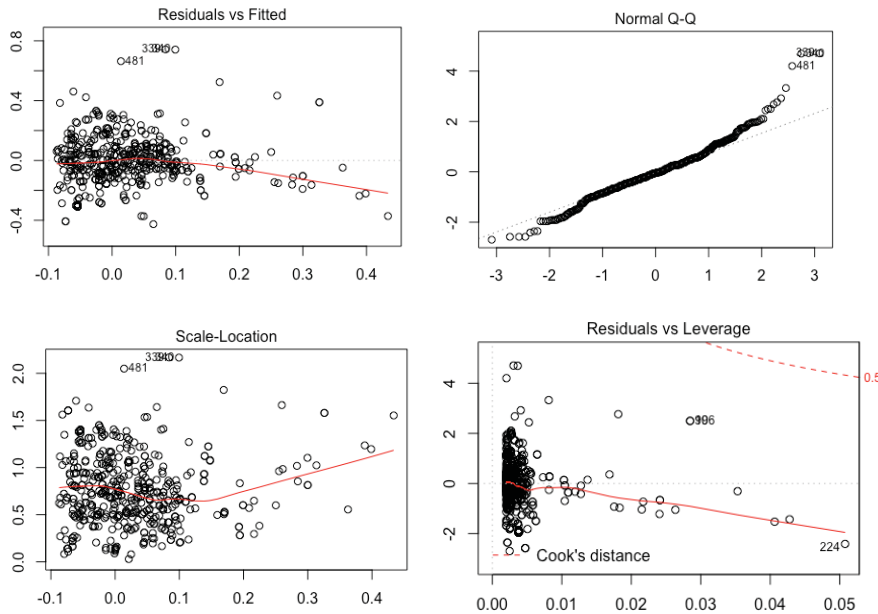
$$\sigma_{\Delta MV_i} = 0.137 + 0.28 \times \Delta EEDI_i + \varepsilon_i$$

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  $\Delta EEDI$ . 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  $\Delta EEDI$ . This could allow for an estimation of the contribution of  $\Delta EEDI$  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

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

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

Equation 8: SOSD

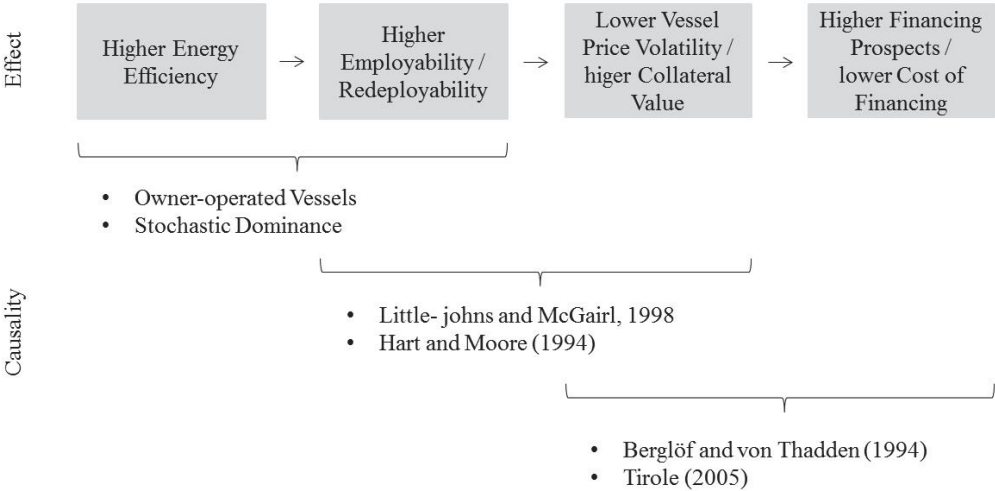
$$\int_{-\infty}^q F_A(z) dz \leq \int_{-\infty}^q F_B(z) dz \quad \forall q$$

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.

## References

- Adland, A.O., Koekebakker, S., 2004. Market efficiency in the second-hand market for bulk ships. *Maritime Economics and Logistics* 6: pp. 1-15.
- Adland, A.O., Koekebakker, S., 2007. Ship valuation using cross-sectional sales data: A multivariate non-parametric approach. *Maritime Economics and Logistics* 9, pp. 105-118.
- Agnolucci, P., Smith, T., Rehmatulla, N., 2014. Energy efficiency and time charter rates: Energy efficiency savings recovered by ship owners in the Panamax market. *Transportation Research Part A: Policy and Practice*, Volume 66, August 2014, pp.173-184.
- Alisafaki, A., Papanikolaou, A., 2015. On the Energy Efficiency Design Index of Ro-Ro passenger and Ro-Ro cargo ships. *Proceedings of the Institution of Mechanical Engineers - Part M, Journal of Engineering for the Maritime Environment*, 2015.
- Ariely, D., 2009. *Predictably Irrational, Revised and Expanded Edition: The Hidden Forces That Shape Our Decision*. Harper Collins, New York.
- Ariely, D., Wallsten, T.S., 1995. Seeking subjective dominance in multidimensional space: an explanation of the asymmetric dominance effect. *Organ. Behav. Hum.* 63.3 (Dec.), pp.223-232.
- Baltic Exchange, 2013. *Baltic Exchange Sale and Purchase Assessment*.
- Bawa, V., 1975. Optimal rules for ordering uncertain prospects. *Journal of Financial Economics*, 2, pp.95-121.
- Bawa, V.S., Bodurtha, J.R., Rao, M.R., Suri, H.L., 1985. On determination of stochastic dominance optimal sets. *Journal of Finance*, XL, 2, pp.417-431.
- Bazari, Z., Longva, T., 2011. *Project Final Report. Assessment of IMO Mandated Energy Efficiency Measures for International Shipping. Estimated Co2 Emissions Reduction from Introduction of Mandatory Technical and Operational Energy Efficiency Measures for Ships*.
- Benmelech, E., Bergman, N., 2008. *Liquidation Values and the credibility of the Financial Contract renegotiation: Evidence from U.S. Airlines*. Working Paper 14059, National Bureau of Economic Research.
- Benmelech, E., Bergman, N.K., 2009. Collateral Pricing. *Journal of Financial Economics* 91, pp.339-360.
- Berglöf, E., von Thadden, E., 1994. Short-term versus long-term interests: capital structure with multiple investors. *Quarterly Journal of Economics* 109, pp.1055-1084.
- Black, F., Scholes, M., 1973. The Pricing of Options and Corporate Liabilities. *Journal of Political Economy*. 81 (3), pp. 637–654.

Bouman, E.,A., Lindstad, E., Rialland, A., Strømman, A.H., 2017. State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping - A review. *Transportation Research Part D*, 52 (2017), pp.408-421.

Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W.-Q., Yoshida, K., 2009. Second IMO GHG study 2009; International Maritime Organization (IMO) London, UK, April 2009.

Burns, M., 2012. Cargill, huntsman corporation and unipek uk set new industry standard on fuel efficiency for chartering vessels; charterers take lead on carbon reductions for the existing fleet.

Cames, M., Graichen, J., Siemons, A., Cook, V., 2015. Emission reduction targets for international aviation and shipping. Date of access: 01/10/2019.  
[https://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL\\_STU\(2015\)569964\\_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL_STU(2015)569964_EN.pdf)

Chen, S., Frouws, K., Van De Voorde, E., 2011. Simulation-based optimization of ship design for dry bulk vessels. *Maritime Economics & Logistics* 13(2), pp. 190-212.

Chia, J.E.M., Chia, A., 2014. Charting a Greener Course in Shipping: Incorporating Environmental Performance Indicators in a Tanker Pool System. World Scientific. Chapter 15.

Clean Cargo Working Group (CCWG), 2016. Collaborative Progress; 2015 Progress Report. Technical Report. BSR (Business for Social Responsibility).

Dhaene, J., Goovaerts, M.J., Kaas, R., 2003. Economic Capital Allocation Derived from Risk Measures. *North American Actuarial Journal*, 7(2), pp.44-56.

Deltamarin Ltd., 2009. Study on tests and trials of the Energy Efficiency Design Index as developed by the IMO. Applicability and Refinement of the EEDI for RoRo, RoPax and Specialized Ships.

Diedrich, A., Busemeyer, J.R., 1999. Conflict and the Stochastic-Dominance Principle of Decision Making. *Psychological Science*, 10(4), pp.353-359.

DNV GL, 2014. LNG as Ship Fuel. Technical Report 1.

Drobetz, W., Richter, T., Wambach, M., 2012. Dynamics of time-varying volatility in the dry bulk and tanker freight markets. *Applied Financial Economics* 22 (16), pp.1367-1384.

Eide, M., Endresen, Ø., Skjong, R., Longva, T., Alvik, S., 2009. Cost-effectiveness assessment of CO<sub>2</sub> reducing measures in shipping. *Maritime Policy & Management*, August 2009, pp. 367-384.

Eide, M.S., Longva, T., Hoffmann, P., Endresen, Ø., Dalsøren, S.B., 2011. Future cost scenarios for reduction of ship CO<sub>2</sub> emissions. *Maritime Policy & Management*, Volume 38, 2011, Issue 1.

European Commission, 2019. Reducing emissions from the shipping sector. Date of Access: 01/10/2019. [https://ec.europa.eu/clima/policies/transport/shipping\\_en](https://ec.europa.eu/clima/policies/transport/shipping_en)

Faber, J., Marowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I., Selstad, E., Kågeson, P., Lee, D., Buhaug, Ø., Lindstad, H., Roche, P., Humpries, E., Graichen, J., Cames, M., 2009. Technical Support for European Action to Reducing Greenhouse Gas Emissions from International Transport. Oude Delft 180, 2611 HH Delft, The Netherlands.

Faber, J., Behrends, B., Nelissen, D., 2011. Analysis of GHG Marginal Abatement Cost Curves. CE Delft, Delft.

Faber, J., Nelissen, D., Ahdour, S., Harmsen, J., Toma, S., Lebesque, L., 2015. Study on the Completion of an EU Framework on LNG-fuelled Ships and its Relevant Fuel Provision Infrastructure; Analysis of the LNG market development in the EU. Technical Report. European Commission.

Fama, E. F., 1965. The behavior of stock-market prices, *Journal of Business* 38(1), pp. 34–105.

Fischer, H., 2011. *A History of the Central Limit Theorem. From Classical to Modern Probability Theory*, New York 2011.

Fishburn, P.C., 1974. Convex stochastic dominance with continuous distribution functions. *Journal of Economic Theory*, 7, pp. 143-158.

Fishburn, P.C., 1980. Stochastic dominance and moments of distributions. *Mathematics of Operations Research*, 5, pp. 94-100.

Gavalas, D., Syriopoulos, T., 2014. Selecting the Optimum Collateral in Shipping Finance. In: *Sustainable Logistics and Strategic Transportation Planning*, Chapter 14.

Greenwood, R., Hanson, S., 2013. Waves in Ship Prices and Investment. Working Paper 19246, NBER Working Paper Series.

Ha, Y.S., Seo, J.S., 2017. An Analysis of the Competitiveness of Major Liner Shipping Companies. *The Asian Journal of Shipping and Logistics*, Volume 33, Issue 2, July 2017, pp. 53-60.

Harris, T.R., Mapp, H.P., 1986. A Stochastic Dominance Comparison of Water-Conserving Irrigation Strategies. *American Journal of Agricultural Economics*, Volume 68, Issue 2, 1 May 1986.

Harrould-Kolieb, E., 2008. Shipping impacts on climate: a source with solutions. [http://www.cleanshipping.org/download/Oceana\\_Shipping\\_Report1.pdf](http://www.cleanshipping.org/download/Oceana_Shipping_Report1.pdf), date of access: 01/10/2019.

Hart, O., Moore, J., 1994. A theory of debt based on the inalienability of human capital. *Quarterly Journal of Economics* 109, pp.841-79.

Huang, C.-F., Litzenger, R., 1988. Foundations for Financial Economics. North-Holland.

Hubert, J., Payne, J.W., Puto, C., 1982. Adding asymmetrically dominated alternatives: violations of regularity and the similarity hypothesis. *Journal of Consumer Research*, Volume 9, Issue 1, 1 June 1982, pp.90-98.

IMO, 2008. Amendments to the Annex of the protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relation thereto (Revised MARPOL Annex VI), Resolution MEPC.176(58), Adopted on 10 October, 2008.

IMO, 2011. Amendments to the Annex of the protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relation thereto (Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI), Resolution MEPC.203(62), Adopted on 15 July, 2011.

IMO, 2012a. 2012 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP), Resolution MEPC.213(63), Adopted on 2 March, 2012.

IMO, 2012b. Guidelines for Calculation of Reference Lines for Use with the Energy Efficiency Design Index (EEDI). Resolution MPEC.215(63). Adopted on 2 March 2012.

IMO, 2014. 2014 Guidelines on the Method of Calculation of the Attained energy Efficiency Design Index (EEDI) for New Ships, Resolution MEPC. 245(66), Adopted on 4 April, 2014.

IMO, 2018. Initial IMO Strategy on Reduction of GHG Emissions from Ships. Resolution MEPC.304(72), Adopted on 13 April 2018.

IMO, 2019. UN agency pushes forward on shipping emission reduction. IMO Briefing 11, 20/05/2019. Date of Access: 01/10/2019.  
<http://www.imo.org/en/MediaCentre/PressBriefings/Pages/11-MEPC-74-GHG.aspx>

Jiang, L., Lauridsen, J.T., 2012. Price formation of dry bulk carriers in the Chinese shipbuilding industry. *Maritime Policy & Management* 39 (3), pp.339-351.

Kavussanos, M.G., 1996a. Comparisons of volatility in the dry-cargo ship sector. Spot versus time-charterers, and smaller versus larger vessels. *Journal of Transport Economics and Policy*, Volume 30, No.1, pp.67-82.

Kavussanos, M.G., 1996b. Price risk modelling of different size vessels in the tanker industry using autoregressive conditional heteroskedastic (ARCH) models. *Logistics and Transportation Review* 32 (6), pp.161-176.

Kavussanos, M.G., 2003. Time varying risks among segments of the tanker freight markets. *Maritime Economics and Logistics*, Vol.V., No.3, pp.227-250.



Kavussanos, M.G., 2010. Business Risk Measurement and Management in the Cargo Carrying Sector of the Shipping Industry – an Update, Chapter 25, pp.709-743 in: The Handbook of Maritime Economics and Business, Lloyds of London Press, London.

Kavussanos, M.G., Alizadeh, A.H., 2002. Efficient pricing of ships in the dry bulk sector of the shipping industry, in: Maritime Policy and Management 29(3): pp. 303-330.

Kavussanos, M.G., Nomikos, N.K., 2000. Constant vs. time-varying hedge ratios and hedging efficiency in the BIFEX market. Transportation Research Part E: Logistics and Transportation Review 36 (4), pp.229-248.

Kavussanos, M.G., Visvikis, I.D., 2004. Market interactions in returns and volatilities between spot and forward shipping freight markets. Journal of Banking and Finance 28 (8), pp.2015-2049.

Keating, C., Shadwick, W.F., 2002. A universal performance measure. Journal of Performance Measurement, 6, pp. 59-84.

Köhn, S., 2008. Generalized additive models in the context of shipping economics. Theses Department of Economics, University of Leicester.

Kollamthodi, S., Brannigan, C., Harfoot, M., Skinner, I., Whall, C., Lavric, L., Noden, R., Lee, D., Buhaug, Ø., Martinussen, K., Skejic, R., Valberg, I., Brembo, J., Eyring, V., Faber, J., 2008. Greenhouse gas emissions from shipping: trends, projections and abatement potential. Final report to the Shadow Committee on Climate Change, AEA Energy, September.

Kopa, M., Moriggia, V., Vitali, S., 2018. Individual optimal pension allocation under stochastic dominance constraints. Annals of Operations Research, Springer, vol. 260(1), pp.255-291.

Li, C.K., Wong, W.K., 1999. A note on convex stochastic dominance theory. Economics Letters, 62, 293-300.

Littlejohns, A., McGairl, S., 1998. Aircraft Financing, third ed. Euromoney Publications, England.

Lonsdale, J., Rayment, M., Rehmatulla, N., Raucci, C., Palmer, K., Palsson, C., Lindstad, E., 2019. A study to estimate the benefits of removing market barriers in the shipping sector. Final report. February, 2019.

Lu, J., Marlow, P.B., Wang, H., 2008. An analysis of freight rate volatility in dry bulk shipping markets. Maritime Policy & Management 35 (3), pp. 237-251.

Lun, Y.H.V., Lai, K.H., Cheng, T.C.E., 2006. Shipping and Transport Logistics.

Lun, Y.H.V., Quaddus, M.A., 2009. An empirical model of the bulk shipping market. International Journal of Shipping Transport & Logistics 1 (1), pp.37-54.

Maddox Consulting, 2012, Analysis of Market Barriers to Cost-Effective GHG Emission Reductions in the Maritime Transport Sector.

Mann, H.B., Whitney, D.R., 1947. On a Test of Whether one of Two Random Variables is Stochastically Larger than the Other. *The Annals of Mathematical Statistics*, Vol. 18, No.1 (March 1947), pp.50-60.

Mayr, D., 2015. Valuing Vessels. *HSBA Handbook on Ship Finance*, pp.141-163.

McAfee, R.P., Lewis, T., 2009. *Introduction to Economic Analysis*, Flatworld Knowledge, 2009.

Meyer, J., 1977. Second degree stochastic dominance with respect to a function. *International Economic Review*, 18, pp.476-487.

Momsen, K., Stoerk, T., 2014. From intention to action: Can nudges help consumers to choose renewable energy? *Energy Policy*, Volume 74, pp.376-382.

Mosler, K., Scarsini, M., 1991. Some theory of stochastic dominance. *Stochastic orders and decision under risk*, pp.261-283, Institute of Mathematical Statistics, Hayward, CA.

Pindyck, R.S., 1984. Risk, Inflation, and the Stock Market. *The American Economic Review*, Vol. 74, No. 3 (June 1984), pp.335-351.

Pruyn, J.F.J., Van De Voordeb, E., Meersmann, H., 2011. Second hand vessel value estimation in maritime economics: A review of the past 20 years and the proposal of an elementary method, *Maritime Economics & Logistics* Vol. 13, 2, pp. 213-236.

Pyle 1997, *Bank Risk Management: Theory*.

Rehmatulla, N., Smith, T., 2015a. Barriers to energy efficiency in shipping: a triangulated approach to investigate the principal agent problem in shipping. *Energy Policy*, 84 (2015), pp. 44-57.

Rehmatulla, N., Smith, T., 2015b. Barriers to energy efficient and low carbon shipping. *Ocean Engineering*, Volume 110, Part B, pp. 102-112.

Rehmatulla, N., Calleya, J., Smith, T., 2017. The Implementation of technical energy efficiency and CO2 emission reduction measures in shipping. *Ocean Engineering* 139, pp. 184-197.

Ross, H.H., Schinas, O., 2019. Empirical evidence of the interplay of energy performance and the value of ships. *Ocean Engineering*, 190 (2019), 106403.

Ruxton, G.D., 2006. The unequal variance t-test is an underused alternative to Student's t-test and the Mann-Whitney U test. *Behavioral Ecology*, Vol. 17, Issue 4, pp.688-690.

Schinas, O., Butler, M., 2016. Feasibility and commercial considerations of LNG-fueled ships. *Ocean Engineering* 122, 84-96.

- Schinas, O., Kewitsch, S., 2015. *Loans and Risk Management Considerations*. Springer Berlin Heidelberg, Berlin, Heidelberg. pp. 33-54.
- Schinas, O., Metzger, D., 2019. A pay-as-you-save model for the promotion of greening technologies in shipping. *Transportation Research Part D: Transport and Environment* 69 (2019), pp.184-195.
- Schinas, O., Ross, H.H., Rossol, T.D., 2018. Financing green ships through export credit schemes. *Transportation Research Part D: Transport and Environment* 65 (2018), pp.300-311.
- Shapiro, S. S., and Wilk, M. B., 1965. An analysis of variance test for normality (complete samples), *Biometrika* 52, pp. 591–611.
- Sharpe, W. F., 1964. Capital Asset Prices: A Theory of Market Equilibrium under Conditions of Risk. *Journal of Finance*, V. 19, September, pp 425-442.
- Skjølvsvik, K.O., Andersen, A.B., Corbett, J.J., Skjelvik, J.M., 2000. Study of Greenhouse Gas Emissions from Ships (MEPC 45/8 Report to International Maritime Organization on the outcome of the IMO Study on Greenhouse Gas Emission from Ships).
- Smith, T., Jalkanen, J. P., Anderson, B. A., Corbett, J. J., Faber, J., Hanayama, S., O’Keeffe, E., Parker, S., Johansson, L., Aldous, L., Raucci, C., Traut, M., Ettinger, S., Nelissen, D., Lee, D. S., Ng, S., Agrawal, A., Winebrake, J. J., Hoen, M., Chesworth, S., Pandey, A., 2014. *Third IMO GHG Study 2014*; International Maritime Organization (IMO) London, UK, April 2015.
- Smith, T., O’Keeffe, E., Aldous, L., Agnolucci, P. (2013). *Assessment of shipping’s efficiency using satellite AIS data*. Washington: ICCT.
- Snedecor, G.W., Cochran, W.G., 1989. *Statistical Methods*, Eighth Edition, Iowa State University Press.
- Sodal, S., Koekebakker, S., Adland, A.O., 2006. Value based trading of real assets in shipping under stochastic freight rates. *Applied Economics* 41(22): pp. 2793-2807.
- Stopford, M., 2009. *Maritime Economics*. Routledge, London. 3rd edition.
- Stott, P., 2014. A retrospective review of the average period of ship ownership with implications for the potential payback period for retrofitted equipment. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment* 2014, 228(3), pp.249-261.
- Stoyan, D., 1983. *Comparison Methods for Queues and Other Stochastic Models*, John Wiley, New York.
- Stulgis, V., Smith, T., Rehmatulla, N., Powers, J., Hoppe, J., 2014. *Hidden Treasure: Financing Models for Retrofits*.
- Syriopoulos, T., Roumpis, E., 2006. Price and volume dynamics in second-hand dry bulk and tanker shipping markets. *Maritime Policy & Management* 33 (5), pp.497-518.

- Tirole, J., 2005. *The Theory of Corporate Finance*. Princeton University Press, Princeton, NJ.
- Tsolakis, S., 2005. *Econometric Analysis of Bulk Shipping Markets; Implications for Investment Strategies and Financial Decision Making*.
- Tsolakis, S.D., Cridland, C., Haralambides, H.E., 2003. Econometric modelling of second-hand shipprices. *Maritime Economics & Logistics* 5 (4), pp.347-377.
- Tsouknidis, D.A., 2016. Dynamic volatility spillovers across shipping freight markets. *Transportation Research Part E: Logistics and Transportation Review* 91, pp.90-111.
- Tvedt, J., 2003. A new perspective on price dynamics of the dry bulk market. *Maritime Policy & Management* 30 (3), pp.221-230.
- UNCTAD, 2017. *Review of Maritime Transport 2017*. United Nations Conference on Trade and Development.
- UNCTAD, 2018. *Merchant fleet by flag of registration and by type of ship, annual, 1980-2018*. United Nations Conference on Trade and Development. Date of Access: 01/10/2019: <http://unctadstat.unctad.org/wds/TableViewer/tableView.aspx?ReportId=93>
- United Nations, 1992. *United Nations Framework Convention on Climate Change*.
- United Nations, 1998. *Kyoto protocol to the United Nations Framework Convention on Climate Change*.
- Veenstra, A.W. and Franses, P.H., 1995. *Modelling and forecasting ocean freight rates*.
- Veenstra, A., Ludema, M., 2006. The relationship between design and economic performance of ships. *Maritime Policy & Management*, 33(2), May 2016.
- Wang, H., Faber, J., Nelissen, D., Russel, B., St Amand, D., 2010. *Marginal Abatement Costs and Cost-Effectiveness of Energy Efficiency Measures*. Institute of Marine Engineering, Science & Technology (IMarEST), London (2010).
- Whitmore, G.A., Findlay, M.C., 1978. *Stochastic Dominance: An Approach to Decision-Making Under Risk*, D.C.Heath, Lexington, MA.
- Wilson, W., Gustafson, C., Dahl, B., 2009. Crop insurance in malting barley: a stochastic dominance analysis. *Agricultural Finance Review*, Vol. 69 Issue: 1, pp.98-112.

**2019**

- 181 Ross, Harm Hauke: Second-hand price volatility of green ships: an empirical analysis across main shipping segments, November 2019

**2018**

- 181 Wenzel, Daniela: Droughts and Corruption, September 2018  
180 Linder, Melissa; Muijs, Matthias: A new price test in geographic market definition – an application to german retail gasoline market, August 2018  
179 Dewenter, Ralf; Linder, Melissa; Thomas, Tobias: Can Media Drive the Electorate? The Impact of Media Coverage on Party Affiliation and Voting Intentions, April 2018

**2017**

- 178 Beckmann, Klaus: Bounded rationality in differential games, December 2017  
177 Herzer, Dierk; Nagel, Korbinian: The effects of adult and non-adult mortality on long-run economic development: Evidence from a heterogeneous dynamic and cross-sectionally dependent panel of countries between 1800 and 2010, July 2017  
176 Dewenter, Ralf; Heimeshoff, Ulrich; Löw, Franziska: Market Definition of Platform Markets, March 2017

**2016**

- 175 Dewenter, Ralf; Dulleck, Uwe; Thomas, Tobias: Does the 4th estate deliver? Towards more direct measure of political media bias, November 2016  
174 Luik, Marc-André: Child Health, Human Capital and Adult Financial Behavior, November 2016  
173 Michael Berlemann; Marc-André Luik: Institutional Reform and Depositors' Portfolio Choice - Evidence from Bank Account Data, November 2016  
172 Lauenstein, Philipp; Küster Simic, André: Information Processing in Freight and Freight Forward Markets: An Event Study on OPEC Announcements, September 2016  
171 Nagel, Korbinian: A Life Course Perspective on the Income-to-Health Relationship: Macro-Empirical Evidence from Two Centuries, July 2016  
170 Dluhosch, Barbara; Horgos, Daniel: International Competition Intensified - Job Satisfaction Sacrificed?, June 2016  
169 Beckmann, Klaus; Dewenter, Ralf; Thomas, Tobias: Can news draw blood? The impact of media coverage on the number and severity of terror attacks, May 2016  
168 Afflatet, Nicolas: Deficit Policy within the Framework of the Stability and Growth Pact - Empirical Results and Lessons for the Fiscal Compact, April 2016  
167 Werner, Max: Evaluating Prediction Markets for Internal Control Applications, May 2016  
166 Werner, Max; Eißing, Klaus; Langton, Sebastian: Shared Value Potential of Transporting Cargo via Hyperloop, May 2016  
165 Werner, Max; Vianelli, A.; Bodek, Mariusz C.: Monitoring Venture Capital Investments through Internal Control Prediction Markets, May 2016  
164 Jahn, Vera; Steinhardt, Max Friedrich: Innovation and Immigration - Insights from a Placement Policy, February 2016  
163 Beckmann, Klaus; Gattke, Susan; Lechner, Anja; Reimer, Lennart: Lineare dynamische Konfliktmodelle: Ein systematischer Überblick, Februar 2016  
162 Beckmann, Klaus; Gattke, Susan; Lechner, Anja; Reimer, Lennart: A critique of the Richardson equations, January 2016

**2015**

- 161 Dewenter, Ralf; Schwalbe, Ulrich: Preisgarantien im Kraftstoffmarkt, Oktober 2015  
160 Afflatet, Nicolas: Fiscal Policy in a Debt Crisis - A Model, June 2015  
159 Beckmann, Klaus; Gattke, Susan; Reimer, Lennart: The Boulding-Richardson Model Revisited, June 2015  
158 Jahn, Vera: The Importance of Mittelstand Firms for Regional Apprenticeship Activity - Lessons for Policy, April 2015  
157 Im Winkel, Niklas: Rechts? Links? Liberal? Egal? Gründe für die Entstehung verzerrter Medieninhalte und Methoden zur Messung des Bias, February 2015  
156 Afflatet, Nicolas: Public Debt and Borrowing. Are Governments Disciplined by Financial Markets?, January 2015

