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Impacts of a bunker levy on decarbonizing shipping: A tanker case study

Sotiria Lagouvardou [a,*], Harilaos N. Psaraftis [a], Thalis Zis [b]

[a] *Department of Technology, Management and Economics, Technical University of Denmark (DTU), Kgs. Lyngby, Denmark*
[b] *Department of Commerce, Finance and Shipping, Cyprus University of Technology, Limassol, Cyprus*

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ABSTRACT

The pressure on shipping to reduce its carbon footprint is increasing. Various measures are being proposed at the International Maritime Organization (IMO), including Market-Based Measures (MBMs). This paper investigates the potential of a bunker levy in achieving short-term CO_2 emissions reductions. The analysis focuses on the tanker market and uses data from the latest IMO GHG studies and a variety of other sources. The connection between fuel prices and freight rates on the one hand and vessel speeds on the other is investigated for the period 2010–2018. A model to find a tanker's optimal laden and ballast speeds is also developed and applied to a variety of scenarios. Results show that a bunker levy, depending on the scenario, can lead to short-term CO_2 emissions reductions of up to 43%. Policy implications are also discussed, particularly vis-à-vis recent IMO and European Union (EU) action on MBMs.

1. Introduction

The International Maritime Organization (IMO) in April 2018 adopted the "Initial IMO Strategy" with an intention to reduce the total annual GHGs from shipping by at least 50% by 2050 compared with 2008 while pursuing efforts towards phasing them out entirely (IMO, 2018). During COP26, 14 nations signed a declaration to bring shipping emissions down to net zero by 2050 (Clydebank, 2021). However, despite the promising governmental initiatives, without a solid regulatory intervention enforced as soon as possible, emissions from ships will continue to rise. The 4th IMO GHG study estimated that in a Business as Usual (BAU) scenario, CO_2 emissions from shipping are expected to grow by 90%–130% vs 2008 levels (Faber et al., 2020).

The candidate measures that have been proposed at the IMO for reaching the emissions targets have been classified into short-term, medium-term and long-term measures. These are to be agreed upon and implemented by 2023, between 2023 and 2030, and after 2030, respectively. Thus far, the focus on short-term measures led to the adoption of the Energy Efficiency Existing Ships Index (EEXI), the Carbon Intensity Indicator (CII), and the strengthening of the Ship Energy Efficiency Management Plan (SEEMP) -see IMO (2021b) for the MEPC 76 decision and Psaraftis (2021) for a discussion. Furthermore, at MEPC 76, medium-term solutions such as Market Based Measures (MBMs) have been re-introduced and various member states and other delegations have submitted their supporting proposals.

We clarify here that even though MBMs are considered medium-term measures, they can have both short-term (logistical) and long-term (technological) impacts, as will be explained below.

MBMs are environmental policies that enforce the "polluter pays" principle and thus provide monetary incentives to stakeholders to reduce their emissions. MBMs were initially proposed to the IMO in 2010 but their discussion was suspended in 2013. They

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[*] Corresponding author.
E-mail address: sotla@dtu.dk (S. Lagouvardou).

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associate with environmental taxes like fossil fuel or carbon taxes and Emissions Trading Systems (ETS) such as the EU ETS. Perhaps the highest-profile MEPC 76 submission on such MBMs has been the one by the Marshall Islands and the Solomon Islands, proposing a levy of 100 USD per metric ton (MT) of CO_2 — equivalent emissions (IMO, 2021a). This is roughly equivalent to about 300 USD/MT of bunker fuel.

In parallel, in July 2021, the European Commission (EC), in the context of the "Fit for 55" package and the "European Green Deal" has proposed to include shipping into the EU ETS (EC, 2021). Compliance with the regulation would require the purchase of emissions allowances for all of the CO_2 emissions of intra-European Economic Area (EEA) trips, 50% of the CO_2 emissions of all trips incoming to the EEA, 50% of the CO_2 emissions from all trips outgoing from the EEA, and all at-berth CO_2 emissions at EEA ports. The final form of such measure will depend on the outcome of negotiations between the various EU regulatory bodies (Commission, Parliament and Council) and maritime stakeholders. For a literature survey on MBMs see Lagouvardou et al. (2020), and for a comparative evaluation of various MBMs see Psaraftis et al. (2021).

In the face of all the recent regulatory developments, most of which are ongoing and thus open, the purpose of this paper is to evaluate the short-term impacts of an MBM in the form of a global bunker levy, and examine as a case study the tanker market, one of the vital sectors of global shipping. We note that in the short-term a levy can cause speed reduction and thus, CO_2 emissions reductions. In the long-term a levy can improve the cost competitiveness of energy saving technologies and alternative fuels and gather revenues that will further enhance the viability and scalability of such technologies and fuels. This paper focuses on the short-term or impacts of a bunker levy on tankers and tries to associate its implementation with the targets set by the Initial IMO Strategy.

The rest of this paper is organized as follows. Section 2 presents a literature review on studies focusing on the effects of a bunker levy on the vessel's speed and GHG emissions. Section 3 explains the rationale behind the choice of tankers as a case study. Section 4 describes the speed optimization problem faced by the ship's operator and Section 5 investigates the correlation between data on bunker prices and spot rates with data on the average speed. Section 6 contains the modeling approach of calculating the optimal vessel's speed on laden and ballast conditions as well as the corresponding equal throughput CO_2 emissions, taking into consideration various market and ship specific parameters. The results of the analysis are presented in Section 7 and a discussion is held in Section 8. Finally Section 9 summarizes the conclusions of this study.

2. Literature review

There is an extensive literature on the influence of a bunker levy on a vessel's service speed and hence on CO_2 emissions. In an early paper not dealing with emissions, Beenstock and Vergottis (1989) developed an econometric model that proved that the ratio of the freight rate to bunker price is a strong determinant of the optimal ship's speed with the latter being an increasing function of that ratio (1962–1986 data). The same conclusion was reached in the speed paper taxonomy of Psaraftis and Kontovas (2013), even though in both cases, the models that were used were rudimentary (for instance, no port times, port costs or port emissions were considered, nor were distinct laden and ballast speeds and fuel consumption taken into account). Section 4 of this paper develops an extended model.

Furthermore, there is a large body in the maritime logistics literature that deals with ship speed optimization problems in which the speed of the vessel stands as a decision variable. To the extent that fuel price is one of the main inputs influencing ship speed, some of these publications also examine, either directly or indirectly, the impact of a bunker levy on ship speed and hence emissions.

Before we discuss these publications, we note that in the context of the evaluation of the 11 MBM proposals put forward to the IMO in 2010, an Expert Group appointed by the IMO Secretary General performed, among other things, some modeling to estimate the GHG emissions reductions associated with each of the MBM proposals (IMO, 2010). The MBM proposal closest to a levy was the so called International Fund for Greenhouse Gas emissions from ships (GHG Fund) proposed by Cyprus, Denmark, the Marshall Islands, Nigeria and IPTA (International Parcel Tanker Association). Most of its emissions reductions would be achieved via out-of-sector reductions. Many scenarios were examined, but no MBM was identified as preferable in the Expert Group's report.

In the context of developing models that optimize the speed of tankers (Gkonis and Psaraftis, 2012) estimated the CO_2 reductions for tankers for a few levy scenarios, and found that a 50% CO_2 emissions reduction for a single Very Large Crude Carrier (VLCC) can be achieved if the levy induces an increase on fuel costs from 400–1000 USD/MT. In an earlier study, Devanney (2011) estimated that with a price of Heavy Fuel Oil (HFO) at 465 USD/MT, a bunker levy at 50 USD/MT would achieve a 6% reduction in total VLCC CO_2 emissions and that a levy of 150 USD/MT would result in an 11.5% reduction.

The paper of Ådland and Jia (2018) is noteworthy in the sense that, after an analysis of fuel prices and ship speed data obtained via detailed satellite AIS (Automatic Identification System) information, the paper concluded that no correlation between fuel prices and ship speed could be found. However, there are some important caveats on that conclusion, for instance, that the model used did not take weather information into account (*"The poor model fit may be due to factors outside our model, such as weather conditions and contractual limitations"*). Further, that paper used detailed AIS data for 1,800 Capesize bulk carriers for 2011 and 2012. However, the 3rd and 4th IMO GHG studies claim that before 2012, due to insufficient AIS coverage, the derived AIS data were highly doubtful and not consistent (more on this in Section 5 of this paper).

Giovannini and Psaraftis (2019) developed an optimization model for a fixed route liner shipping scenario which, among other parameters, incorporated the influence of fuel prices and freight rates into the overall decision process. A flexible frequency scenario was considered and it was seen that increases in fuel prices significantly reduce speeds and, therefore, CO_2 emissions in the container sector.

Last but not least, Psaraftis (2019) compared speed limits with a bunker levy. The paper concluded that even though both measures can reduce GHG emissions, speed limits entail various distortions and would not incentivize improvements in energy efficiency. For a rudimentary containership scenario, he estimated that on a base bunker price of 500 USD/MT, a levy of equal magnitude would achieve 50% reductions in CO_2, also taking into account the CO_2 emitted by the extra ship capacity deployed to maintain throughput.

In spite of all of the above, it is fair to say that none of the studies we have reviewed has attempted to link any of the IMO GHG studies with real market-specific and on a fleet level data or to investigate the possible short-term impact of MBMs on a fleet-level basis. The most recent study that in many ways can be considered as the most definitive statement on where the shipping industry stands and where it may be going as regards GHG emissions is the 4th IMO GHG Study (Faber et al., 2020). None of the above referenced papers were linked with this study or the three previous IMO GHG studies. In fact, the 4th IMO GHG study, even though it includes a wealth of data and related analyses from a multitude of angles, including an investigation of a spectrum of GHG abatement technologies and other measures in the quest to meet the 2050 50% reduction target, *did not* consider MBMs or their possible impact on GHG emissions. So in our view there is a gap in the current body of knowledge, which this paper attempts to address.

To do so, our analysis (a) develops an optimization model that determines optimal laden and ballast speeds for a tanker as functions of fuel prices and freight rates, (b) investigates the historical relationship between fuel prices and freight rates on the one hand and ship speed on the other, by combining for the first time data from various sources including the WorldScale (WS) tanker database, Drewry reports on tanker freight rates, the 3rd and 4th IMO GHG studies, and the UNCTADStat database, and (c) uses the optimization model to estimate CO_2 emissions for various bunker levy scenarios and for the main size classes of the world tanker fleet. These results show that, a bunker levy can, under proper circumstances and depending on the scenario, lead to short-term CO_2 emissions reductions ranging from 1% to 43%. Even though these may be significant in the short to medium term, they are not deemed sufficient to reach the 2050 reduction target, and the main projected impact of MBMs in that regard is the long-term impact, that is, to incentivize the development of alternative fuels and other energy saving technologies.

The main novelty of the approach in this paper is the utilization of the above data sources that have never been used before in combination. Those sources allowed us to estimate the required level of the bunker levy needed to achieve CO_2 emissions reductions by inducing speed reduction in the short term. In addition, we prove several properties of the speed optimization problem for tankers, and we use the related profit maximization model to estimate CO_2 emissions reductions for various tanker scenarios. In terms of results, we shall see that in case of poor market conditions the imposition of a high levy will not induce emissions reductions in the short term and, thus, will not serve its purpose as a cost effective way for the stakeholders to strive for emissions reductions. In that case, the additional financial burden will increase transportation costs extensively and may lead to modal shifts and carbon leakage because the consumer may opt for cheaper solutions through more energy intensive modes of transport. Conversely, in prosperous periods with high freight rates, a low levy will not induce any significant emissions reductions in the short term and, thus, further postpone the urge to achieve emissions reductions as soon as possible. In this case, the decarbonization goals of the IMO may not be reached on time and there will be no significant incentivization of the shipowners to invest in low carbon technologies and alternative fuels solutions for their fleet. Therefore, this study aims at directing policy makers for the level of the levy needed to be imposed in the market highlighting the importance of the different parameters that will affect its effectiveness.

3. The tanker case study: preamble

Before we proceed, some words are necessary on the tanker market that was chosen as the case study for this paper.

According to the 4th IMO GHG study (Faber et al., 2020), three sectors remain the dominant source of GHG emissions: containers, bulkers and oil tankers, in that order. Containerships are first in the inventory of international shipping GHG emissions, mainly because of their higher service speed, followed by bulk carriers and oil tankers.

As noted earlier, two main determinants of ship speed are *fuel prices* and *freight rates*. Accurate and reliable fuel price information is generally available via various sources worldwide. However, the picture regarding freight rate data is generally more complex and diverse, and the accuracy, consistency and quality of information on freight rates generally depends on the shipping market under consideration.

The tanker market, the shipping market that carries the bulk of the world's petroleum needs, is perhaps unique among all shipping markets in being a relatively homogeneous and competitive market, with the WS index providing accurate and reliable information about tanker spot rates (the freight rates for a voyage charter). It is admitted that the WS index has historically worked well on reflecting the overall spot rate fluctuations of the tanker market. As such, and mainly because of this, we decided that the oil tanker market should be a prime candidate for our analysis.

The dry bulk market is based on very much similar operational principles as the tanker market, however the structure of the dry bulk freight rates is more complex, mainly due to the existence of several distinct commodity markets that make the sector less homogeneous (with iron ore, coal, and grain being the major ones). Its study, important as it is, warrants a separate analysis, which will not be reported here.

Last but not least, the container sector, whose economic and logistical governance is very different from that of the tanker and dry bulk sectors, also merits separate treatment, since the speed decision has to also take into account the network design and scheduling constraints that are prevalent in liner shipping.

4. Research methodology

This section develops an optimization model that optimizes laden and ballast speeds for a tanker. The model extends the earlier work of Devanney (2011) and of Psaraftis and Kontovas (2013). We shall prove that some properties of the earlier, simpler approaches are valid for the extended model but some other properties are not valid in the extended model. In their study, Gkonis and Psaraftis (2012) developed a similar model, but did not enter into any discussion about the properties of the optimization problem in the extended model, particularly with regard to the owner vs. charterer problem, or with respect to the role of the ratio $\varrho = s/p$, or as regards which other factors influence the speed decision. Further, they did not link their research to any GHG study or to data on global vessel speeds, WS freight rates and fuel prices. Their discussion of a bunker levy was only a small part of their paper and that involved a single VLCC and did not investigate the additional emissions arising from providing more capacity to match the loss of throughput due to speed reduction.

Devanney (2011) proved that regardless of the ship's charter type, the owner's and time charterer's speed optimization problems are mathematically equivalent, for a rudimentary chartering scenario. In fact, for a given ship, the speed that maximizes the profit per day for a shipowner in the spot market is the same as the speed that minimizes the average daily costs for a time charterer or a bareboat charterer. The proof roughly goes as follows:

For a voyage chartered vessel the speed optimization problem faced by the shipowner is :

$$\max_{v}\left\{ s\,\frac{12\,L\,v}{d} - p f(v) - E \right\} \tag{1}$$

where:

s = Spot rate in USD/MT
L = Payload in MT
d = One way distance in nautical miles (nm)
v = Sailing speed in knots
p = Bunker price in USD/MT
$f(v)$ = Daily fuel consumption function at speed v in MT/day
E = Operating expenses borne by the ship owner other than fuel costs including crew wages, insurance, and others, also known as OPEX in USD/day

This very simple model ignores port time, port costs, and port fuel consumption and assumes the same speed and the same "at sea fuel consumption" in the laden and ballast conditions. We shall extend this model later.

For a time chartered vessel the speed optimization problem faced by the charterer is the following:

$$\min_{v}\left\{ s\left(W - \frac{12\,L\,v}{d}\right) + p f(v) + C \right\} \tag{2}$$

where:

W = Cargo transferred by the charterer (MT/day)
C = Time charter rate paid to the owner (in USD/day)

Eq. (2) above assumes that any difference between the cargo capacity required by the time charterer W and what the chartered ship can provide if sailing at speed v, i.e. $(12\,L\,v/d)$ can be chartered in the spot market at a spot rate of s. Suppose the difference $(W - 12\,L\,v/d)$ is positive (meaning that the chartered ship sailing at speed v cannot fully satisfy the charterer's needs). In that case, additional capacity is chartered in at a rate of s, assuming the spot chartered ship sailing at the same speed v. If this difference is negative (meaning that here is spare capacity in the time chartered ship), then that spare capacity can be chartered out at the same spot rate s. It is easy to see that the term E in Eq. (1) and the term $sW + C$ in Eq. (2) can drop out as independent of speed and that after some algebraic manipulations, the two optimization problems are mathematically the same. As shown by Psaraftis and Kontovas (2013), factoring out the bunker price p, both problems can be rewritten as follows:

$$\min_{v}\left\{ \frac{f(v)}{\varrho} - \frac{12\,L\,v}{d} \right\} \tag{3}$$

where $\varrho = s/p$ the ratio of the spot rate divided by bunker price.

Based on the above, and for this simple model, the speed optimization problem's key determinant parameter is the non-dimensional ratio $\varrho = s/p$ of the spot rate divided by the bunker price. Higher ϱ ratios will generally induce higher speeds than lower ϱ ratios.

Devanney's simple model can be readily extended to account for non-zero port times and port costs, different laden and ballast speeds and fuel consumption functions, both at sea and in port. The following analysis investigates whether the ship owner's and charterer's optimization problems continue to be mathematically equivalent in the extended version and whether the non-dimensional ratio ϱ continues to be a key driver of the speed decision.

The extension goes as follows for the ship owner's problem:

We assume two sailing speeds, v_l the vessel's laden speed and v_b the vessel's ballast speed in knots. We assume also two at sea fuel consumption functions, $f_l(v_l)$ in laden condition and $f_b(v_b)$ ballast condition (MT/day). Furthermore, port time is Q in days per port call, and the port cost is Z in USD per port call.

In the extended model p is the price of the fuel used by the main engine for propulsion purposes in USD/MT. The auxiliary engines and boilers are assumed to be burning fuel at a price p^* (not necessarily equal to p) and that they have a fuel consumption of f^* at sea, and f^{**} in port in MT/day. f^* and f^{**} are not necessarily the same, even though it is expected that $f^* \geq f^{**}$. Incidentally, the reason we included emissions at port is that according to the 4th IMO GHG study "oil tankers have on average the largest portion of their total emissions (greater than 20%) associated with phases at or near the port or terminal". Those emissions should be included under any global regulation that will serve as a measure to reach the IMO GHG emissions reduction goals.

Then on a per round-trip basis:

$$\text{Roundtrip time} = \overline{RT} = \frac{d}{24v_l} + \frac{d}{24v_b} + 2Q \tag{4}$$

$$\text{Roundtrip income} = \overline{RTI} = sL \tag{5}$$

$$\text{Roundtrip M/E fuel consumption} = \overline{RT\mathcal{F}} = \frac{f_l(v_l)d}{24v_l} + \frac{f_b(v_b)d}{24v_b} \tag{6}$$

$$\text{Roundtrip fuel cost} = \overline{RTFC} = p \cdot \overline{RT\mathcal{F}} + p^* f^* \left(\overline{RT} - 2Q\right) + 2p^* f^{**} Q \tag{7}$$

$$\text{Roundtrip total cost} = \overline{RTTC} = p \cdot \overline{RT\mathcal{F}} + p^* f^* \left(\overline{RT} - 2Q\right) + 2p^* f^{**} Q + 2Z + E \cdot \overline{RT} \tag{8}$$

$$\text{Roundtrip profit} = \overline{RTP} = sL - p\,\overline{RT\mathcal{F}} - p^* f^* \overline{RT} - 2p^*(f^{**} - f^*)Q - 2Z - E \cdot \overline{RT} \tag{9}$$

$$\text{Roundtrip profit/day} = \overline{RTPD} = \frac{\overline{RTP}}{\overline{RT}} = \frac{sL - p \cdot \overline{RT\mathcal{F}} - 2p^*(f^{**} - f^*)Q - 2Z}{\dfrac{d}{24v_l} + \dfrac{d}{24v_b} + 2Q} - E - p^* f^* \tag{10}$$

The expression of Eq. (10) is to be maximized with respect to speeds v_l and v_b, which may have upper and lower bounds. Note that the term $-E - p^* f^*$ is a constant and can be dropped. Therefore E does not influence the speed decision. If $f^* = f^{**}$, then p^*, f^*, and Q do not influence the speed decision either.

The equivalent problem for the charterer can be expressed as follows:

$$\text{Roundtrip cost/day} = \overline{RTCD} = sW + C + p^* f^* + \frac{-sL + p \cdot \overline{RT\mathcal{F}} + 2p^*(f^{**} - f^*)Q + 2Z}{\overline{RT}} \tag{11}$$

The expression of Eq. (11) is to be minimized with respect to speeds v_l and v_b, which may have upper and lower bounds. Note that the term $sW + C + p^* f^*$ is a constant and can be dropped. Therefore W and C do not influence the speed decision. If $f^* = f^{**}$, then p^*, f^*, and Q do not influence the speed decision either.

After the above constant terms are dropped, it can be seen that the objective functions defined by Eq. (10) and by Eq. (11) are mathematically the same, thus proving that the result of Devanney (2011) showing that the two speed optimization problems are equivalent, is also valid in the extended model.

However, another result of Psaraftis and Kontovas (2013) (per Eq. (3)) is that optimal speed is solely a function of the ratio $\varrho = s/p$ and does not change if this ratio is kept constant. This is not necessarily valid here, as shown below.

In fact, if in Eq. (10) we factor out the fuel price p, after omitting the constant term $-E - p^* f^*$, we get the following expression to be maximized with respect to laden and ballast speeds:

$$\Psi = \frac{\left\{ L\varrho - \overline{RT\mathcal{F}} - \dfrac{2Z - 2p^* Q(f^{**} - f^*)}{p} \right\}}{\overline{RT}} \tag{12}$$

Note that both the numerator and denominator of Eq. (12) are non-linear functions of the ship's laden and ballast speeds.

With $\varrho = s/p$ in Eq. (12), it can be seen that only if $Z = 0$ and $f^{**} = f^*$ will the optimal laden and ballast speeds solely depend on the ratio $\varrho = s/p$ and not on the absolute values of s and p. Otherwise, this is not the case.

Mathematics aside, and depending on the values of the input parameters in Eq. (12), we note that from a practical perspective the ratio $\varrho = s/p$ may still be a good ratio to use and investigate how it may relate to ship speeds. This is particularly true if the term $L\varrho - \overline{RT\mathcal{F}}$ is the dominant term in the numerator of Eq. (12). If the rest of the terms are dropped (and this would entail an approximation), then the optimal laden and ballast speeds would depend only on the ratio $\varrho = s/p$. Using this ratio might also be relevant in cases there is no data to differentiate between laden and ballast speeds. In that sense, we shall be revisiting this ratio in some of the analyses in the rest of the paper.

As a last note, in the above analysis it was assumed that both laden and ballast speeds can be freely chosen. If laden speed is fixed (for instance, determined by the charter party contract), then that speed does not enter the optimization problem as a decision variable but as a constant. All properties derived above remain valid.

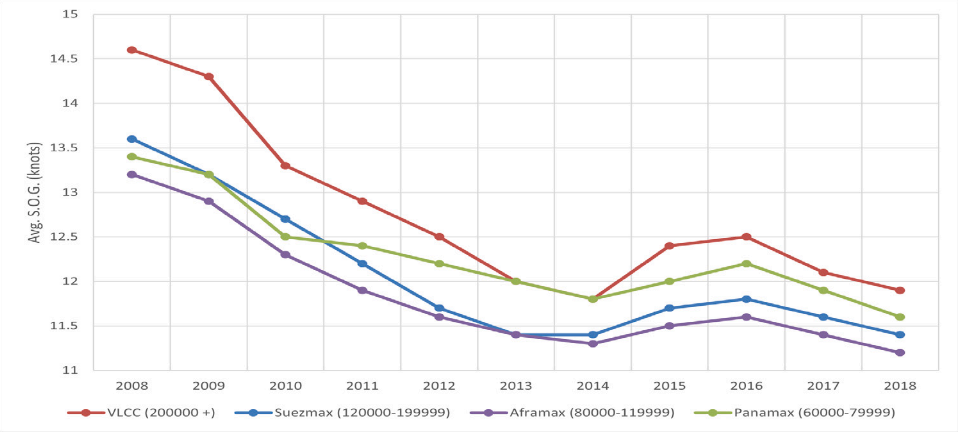

Fig. 1. Evolution of the average SOG for various oil tanker sizes.
Source: (Smith et al., 2015), Faber et al. (2020).

5. Validation with data

The mathematical analysis described in Section 4 has also been observed in practice. According to the 2nd and the 3rd IMO GHG study (Buhaug et al., 2009; Smith et al., 2015), much of the reduction of GHGs from 2007 to 2012 is attributed to slow steaming due to depressed market conditions from 2008. On the other hand, during the COVID-19 outbreak, the resulting precipitous drop of fuel prices in early 2020 led several container carriers on the Far East to Europe trade to sail faster, choosing the longer route around Africa and thus, generating more CO_2 emissions (Psaraftis et al., 2021). Further, as (Cook, 2021) claimed, the significant rise in bulk carrier freight rates in 2021 has led to an increase in ship speeds in the sector.

Another important factor is that, historically, fluctuations on fuel prices have strongly influenced the developments on newbuilding designs. As documented by Stopford (2009), in the early 1970s, when oil prices were low, large vessels were fitted with gas turbines, benefiting from the higher power output and the lower maintenance costs regardless of the higher fuel consumption. However during 1970–85, when fuel prices increased by 950%, many resources were poured into designing more fuel-efficient ships and adjusting the existing operating practices. The result of that bunker price spike was that fuel oil consumption fell sharply. Furthermore, according to the study of Faber et al. (2016) in the 1980s design efficiency of ships improved by up to 28%. In 1986 bunker prices tumbled together with the level of interest and during the 1990s, design efficiency deteriorated by over 10%. The same study showed that in the 1980s and 1990s, the bulkers' Estimated Index Value (EIV) – a design efficiency index for newbuilding ships – was up to 10% better than 1999–2008. However, the efficiency improvements stalled in 2016 when the bunker prices fell sharply at approx. 200 USD/MT (Hoen and Faber, 2017).

Section 5 seeks to use data from various sources to examine possible links between market conditions and operational decisions so that one can investigate the potential of a bunker levy in achieving speed and thus emissions reductions in the short term. We gathered data from 2010 to 2018 on both tanker spot rates and bunker prices, along with data on average speeds, and tried to assess the effects (if any) of the non-dimensional ratio $\varrho = s/p$ on the ship's speed. The segregation of the global tanker fleet followed the 4th GHG study principles. To our knowledge, ours is the first attempt to combine the above kinds of data to seek a connection between freight rates and fuel prices on the one hand, and ship speeds on the other.

5.1. Data collection

5.1.1. Ship speed data

Data on the average annual SOG were retrieved from the 3rd and the 4th IMO GHG study (Smith et al., 2015; Faber et al., 2020) as depicted in Fig. 1. The studies collected the reported SOGs through AIS data.

SOG data as compiled by the IMO GHG studies are averages over a specific fleet segment (for instance, all VLCCs) and over a year. Before using these speeds, we looked at individual ship AIS SOG data, such as for instance those indicatively shown for a specific VLCC in Fig. 2 for the period 2014 to 2021. Also shown in the figure is the time series of the ship's draft, which may provide an indication on which segments the ship was laden and on which the ship was sailing ballast.

We found that individual ship AIS SOG data were not very useful for our analysis, because each series depends on a multitude of exogenous factors such as weather conditions, for which data are not readily available. What proved to be more valuable were the average AIS SOG data, as reported in the various IMO GHG studies.

It is also worth mentioning that according to the 4th GHG study, before 2012, due to insufficient AIS coverage, data on the average SOGs were filled through extrapolations and various assumptions. To that extent, some results around that year might lead to discrepancies that were eventually eliminated with the improvement and expansion of the AIS from approx. 38% global coverage in 2012 to 60% in 2018. This may explain the stronger link among the data in the latest years (Faber et al., 2020).

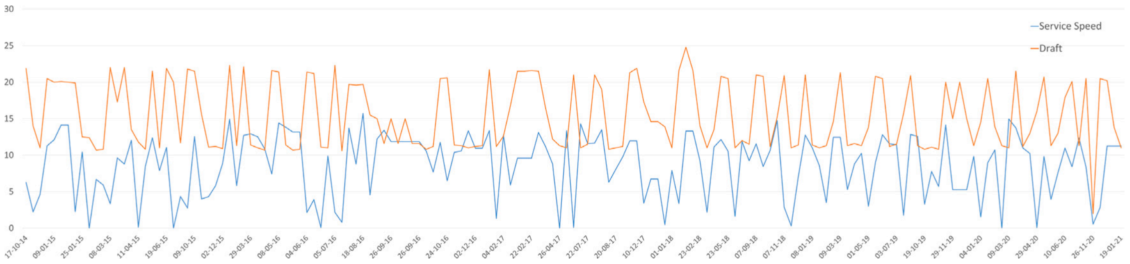

Fig. 2. AIS data for speed and draft for a VLCC. Source: MarineTraffic.

Table 1
Evolution of average bunker prices for the Rotterdam bunker station (2010–2018).
Source: OilMonster website.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
IFO380 (USD/MT)	448.86	614.69	635.40	594.32	533.11	263.40	212.60	304.20	403.35
MGO (USD/MT)	682.21	938.24	945.54	899.83	816.19	477.59	380.17	470.30	614.88

Table 2
Evolution of the freight rates for various major trade routes (2010–2018).
Source: Drewry and the WS website

Tanker Class	Route		2010	2011	2012	2013	2014	2015	2016	2017	2018
VLCC	Ras Tanura–Chiba (AG-JAP)	WS	71	54	48	41	49	63	60	58	55
		Flat Rate (USD/MT)	17.65	22.61	26.95	29.40	27.56	26.95	19.34	14.91	17.72
		Spot Rate (USD/MT)	12.53	12.21	12.94	12.05	13.50	16.98	11.60	8.65	9.75
Suezmax	Novorossiysk–Rotterdam (BK/Med - NEW)	WS	104	87	72	64	82	92	84	89	96
		Flat Rate (USD/MT)	12.60	14.97	17.60	18.94	18.03	17.74	13.47	10.72	12.41
		Spot Rate (USD/MT)	13.10	13.02	12.67	12.12	14.78	16.32	11.31	9.54	11.91
Aframax	Mina Al Ahmadi–Singapore (AG-EAST)	WS	115	116	99	95	108	118	101	118	109
		Flat Rate (USD/MT)	11.06	13.35	15.90	17.37	16.42	16.15	11.76	9.12	10.83
		Spot Rate (USD/MT)	12.72	15.49	15.74	16.50	17.73	19.06	11.88	10.76	11.80
Panamax	Ras Tanura–Yokohama (AG-JAP)	WS	133	126	116	101	111	118	98	120	113
		Flat Rate (USD/MT)	18.42	22.33	26.65	29.10	27.26	26.62	19.06	14.67	17.45
		Spot Rate (USD/MT)	24.50	28.14	30.91	29.39	30.26	31.41	18.68	17.60	19.72

Furthermore, in their study, Psaraftis and Kontovas (2020) argued that the average SOGs published in the 4th IMO GHG study is only an approximation of the actual *Speed Through Water* (STW) which determines better fuel consumption as it includes the effects of currents and tides. On an aggregate basis, the STW is a more informative indicator as it reflects the actual global trends in ship speeds and their correlation to the market condition. However, STW information is typically not available via AIS, therefore SOG is used as a proxy of the vessel's speed.

5.1.2. Fuel price data

The data used to include average fuel prices in our analysis were retrieved from the OilMonster[1] website for the Rotterdam bunker station.Of course, bunker prices in other supply locations are expected to be different, however the trends (price increases or decreases) are generally similar, therefore using Rotterdam bunker station data causes no loss of generality (see Table 1).

5.1.3. Spot rate data

Spot rates were retrieved from (Drewry Maritime Research, 2010-2018) reports on the " Monthly Analysis of the Shipping Markets " in the non-dimensional WS index. For the sake of our analysis, we also converted these data according to the WS database[2] into USD/MT of payload. We utilized the published annual flat rates for the routes under scope found on the WS website.

Table 2 shows some indicative spot rate data for various major trade routes and major tanker classes for the period 2010–2018.

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[1] https://www.oilmonster.com/

[2] https://www.worldscale.co.uk/

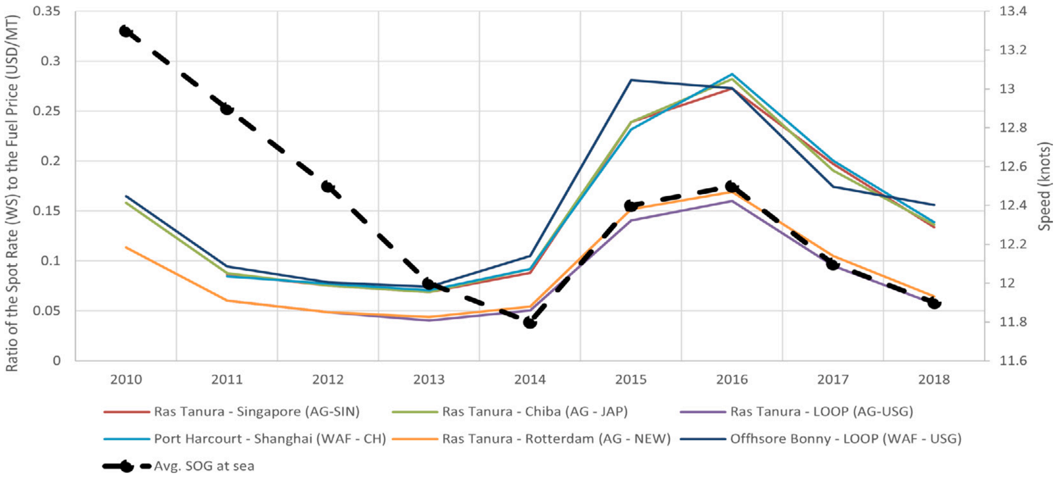

Fig. 3. Evolution of the ratio of spot rates to the fuel price and speed for VLCCs.

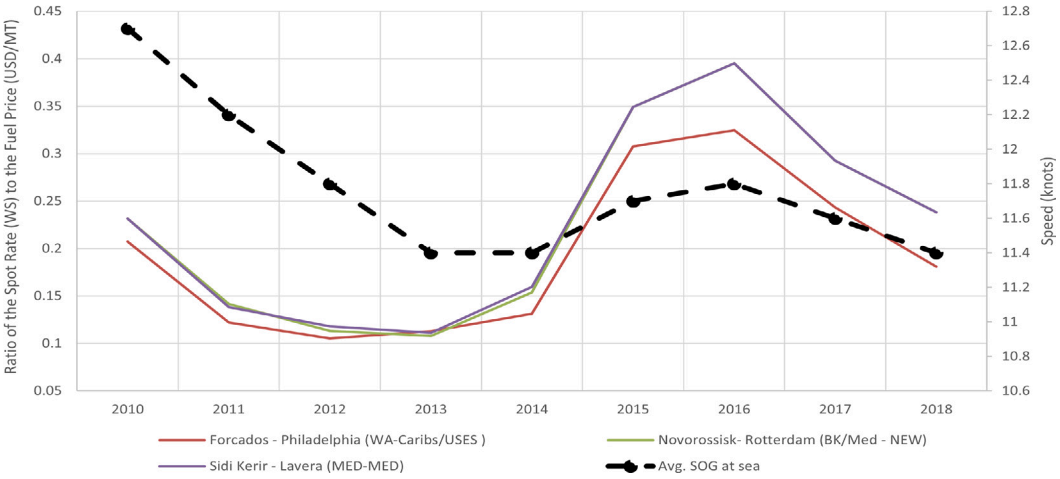

Fig. 4. Evolution of the ratio of spot rates to the fuel price and speed for Suezmax vessels.

5.2. Data analysis

We sought to correlate the average SOG and the ratio of the spot rate (expressed in WS) divided by the fuel price ($\varrho = s/p$). Figs. 3, 4, 5, and 6 show these results for VLCCs, Aframax, Suezmax, and Panamax vessels, respectively, for several major routes. The correlation of $\varrho = s/p$, plotted in the left y-axis to the average SOG plotted in the right y-axis appears to be strong with the inputs being positively correlated, especially from 2014 to 2018. Conversely, from 2010 to 2014, the correlation appears weaker, which may be attributed to insufficient SOG data due to scarce AIS coverage during that period.

Finally, given our access to flat rates data from the WS database, we experimented by plotting the spot rate in USD/MT instead of the WS index. However, the outcome of this investigation showed that the correlation between these inputs was weaker, indicating that, possibly, the WS index is a better indicator for the tanker freight market.

Our statement in Section 3 that the dry bulk sector follows the same operational principles with the tanker sector is also verified by Fig. 7 where it can be seen that the correlation between the non-dimensional ratio of the dry bulk spot rate to the fuel price with the average speed for the case of Capesize ships appears just as strong as for the tanker market. A focused analysis on bulk carriers is ongoing and will not be reported here.

Following the above results, we quantified the ratio's correlation to each tanker segment's speed for the known routes focusing on the data after 2014. Realizing that the number of points in the regression is small, which renders these results not particularly strong from a statistical perspective, we observe that the R^2 values presented in Table 3 for VLCCs were, in both cases, high. Counter-intuitively, the linear regression shows a better R^2 than the power regression.

In summary, despite the above caveats and limitations that mainly concern AIS data quality which limit our analysis, we believe that the above analysis provides strong clues that market conditions remain a crucial driver of operating speeds and, therefore, fuel

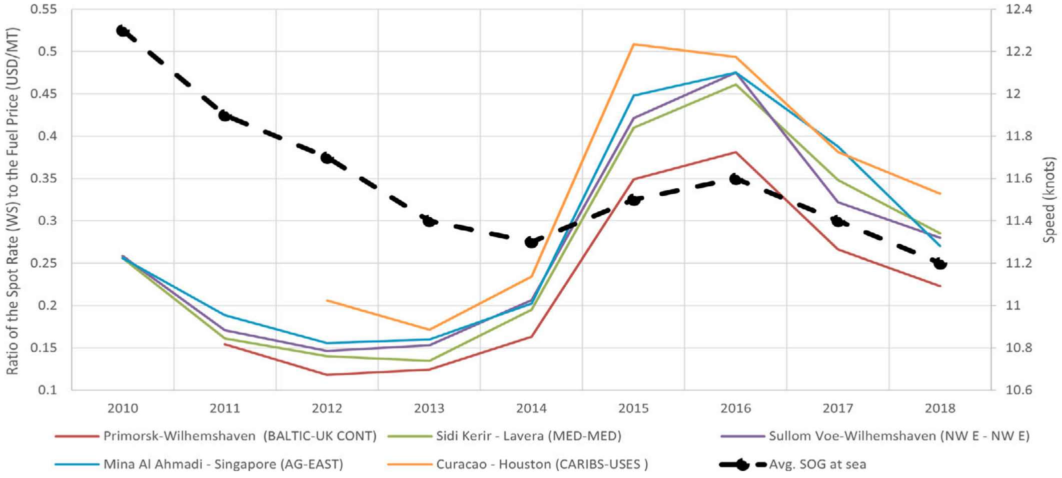

Fig. 5. Evolution of the ratio of spot rates to the fuel price and speed for Aframax vessels.

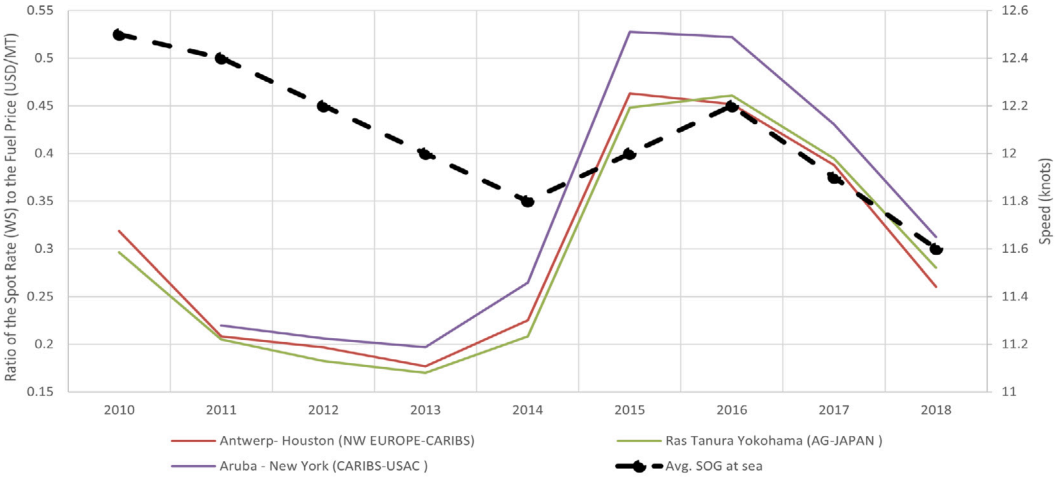

Fig. 6. Evolution of the ratio of spot rates to the fuel price and speed for Panamax vessels.

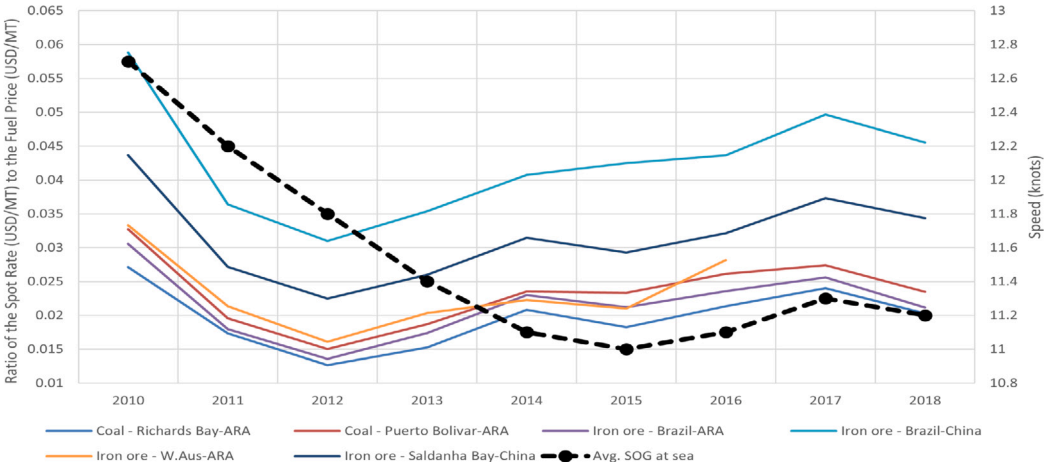

Fig. 7. Evolution of the ratio of spot rates to the fuel price and speed for Capesize vessels.

Table 3
Results of regression for VLCCs.

Route	Linear Regression y = a*x+ b			Power Regression y = c*x^d		
	a	b	R^2	c	d	R^2
Ras Tanura-Singapore	3.969	11.401	0.9645	13.294	0.0518	0.9047
Ras Tanura-LOOP	6.230	11.513	0.9944	13.622	0.0481	0.9836
Ras Tanura-Rotterdam	5.955	11.491	0.9968	13.602	0.0493	0.9803
Ras Tanura-Chiba	3.939	11.399	0.9761	13.332	0.0538	0.9302
Port Harcourt-Shanghai	3.873	11.404	0.9465	13.305	0.0529	0.9008
Offshore Bonny-LOOP	3.888	11.371	0.9519	13.401	0.0588	0.9303

Table 4
Profit maximization model inputs categorized by ship class.

Parameters					
Type of Ship	VLCC (200000+)	Suezmax (120000–199999)	Aframax (80000-119999)	Panamax (60000-79999)	UoM
Distance	Different Scenarios				nm
Laden Speed	Constrained from 10 to 15 knots				knots
Ballast Speed	Constrained from 10 to 15 knots				knots
Spot rate	Drewry Worldscale on max. min. avg. spot rates (2010–2018)				USD/MT
Levy	Different Scenarios (range from 0 to 600 USD/MT)				USD/MT
HFO price	403.4				USD/MT
MGO price	615				USD/MT
HFO Emission Factor	3.114				MT of CO_2/MT of fuel
MGO Emission Factor	3.206				MT of CO_2/MT of fuel
Payload	270000	155000	108000	73000	MT
F. C. laden at serv. speed	$0.0311 * v_l^{2.962}$	$0.0214 * v_l^{3.0836}$	$0.0145 * v_l^{3.1504}$	$1E-05 * v_l^{5.7033}$	MT/day
F. C. ballast at serv. speed	$0.0078 * v_b^{3.3647}$	$0.0022 * v_b^{3.8275}$	$0.0036 * v_b^{3.5848}$	$1E-05 * v_b^{5.6547}$	MT/day
Time at port	5.5	5	4.5	4	days
HFO avg. Generators	5.6	4.7	3	2.7	MT/day
HFO avg. Aux. boilers	4.8	4.3	2.5	2.3	MT/day
MGO avg. Generators	0.2	0.18	0.12	0.09	MT/day
MGO avg. Aux. boilers	0.64	0.6	0.43	0.3	MT/day
OPEX	9950	8041	7832	8041	USD/day
Port costs	50000	40000	30000	20000	USD/entry into port
Operating days per year	352	357	350	323	days

consumption and GHG emissions. The fact that we managed to find even some hints of correlation between market conditions (fuel prices and freight rates) and average operating speeds, as recorded in the various IMO GHG studies, and with all data taken from independent sources, is noteworthy. This also points to the potential value of a bunker levy as a market instrument to influence ship speeds and, therefore, GHG emissions as a short-term impact.

6. Optimization model inputs

Following our analysis, we applied the optimization model developed in Section 4 to a variety of scenarios, with the bunker levy being the main parameter. We ran the model with ship and market-specific inputs and calculated the optimal laden and ballast speeds assuming per day profit maximization. In addition, since the estimation of CO_2 emissions depends on the vessel's loading condition, we calculated two separate fuel consumption functions for the ballast and the laden leg. Sailing laden the ship's higher draft increases the hull's frictional and wave resistance and, thus, the power needed to reach the desired speed. In Section 5, speed data were retrieved from the 3rd and 4th IMO GHG study in which there is no segregation between the two loading conditions and no reporting of separate laden and ballast speeds.

Our model examines several roundtrip voyages for various routes and tanker sizes with the vessel sailing laden from the port of origin to the discharge port and ballast on the return leg. The respective outputs are the optimal laden speeds, the optimal ballast speeds, and the final "equal throughput" CO_2 emissions (for an explanation see Section 7). Table 4 summarizes the values of the various inputs used in our model.

Freight rates were derived after a statistical analysis on the Drewry data used in Section 5 for a minimum, maximum and average level of spot rate for each of the examined routes and tanker size scenario. We used "baseline" bunker prices for 2018 as retrieved at the OilMonster website, to which we added the bunker levy. We studied a dataset of noon reports from 80 tanker vessels of various sizes during the period 2010–2018 to estimate two fuel consumption functions in ballast and laden conditions. Our equations were derived as an extrapolation of speed, draft, and fuel consumption data. Finally, flat rates and the corresponding distances between the ports of interest were retrieved from the WS website.

As per Section 4, the model calculates the optimum combination of ballast and laden speed under the operator's profit maximization target considering all parameters that constitute the annual revenues and expenses. The range of the examined speed values was constrained from 10 to 15 knots with one decimal place accuracy. The average payload per tanker's size category was

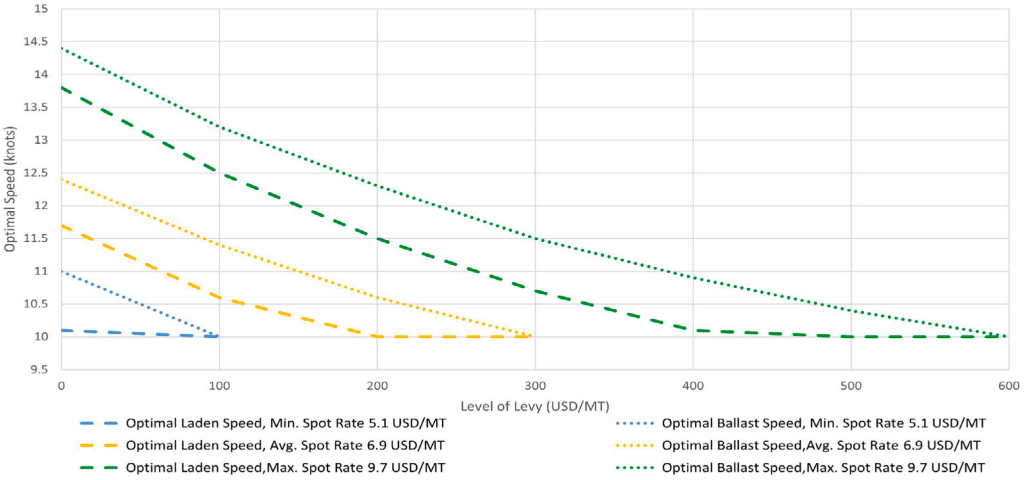

Fig. 8. Optimal laden and ballast speed for different levy and spot rate scenarios for a VLCC sailing from Ras Tanura to Singapore.

taken as a statistical average from the noon reports during the laden leg. Spot rates were initially retrieved from the Drewry Reports in the WS index and then, for the sake of the analysis, were converted to USD/MT based on the annual flat rates of the WS website. The average days spent at port per port call for each segment were retrieved from the UNCTADstat[3] database and were combined with real-time data from the noon reports. Furthermore, our analysis considered the fuel consumption of the auxiliary equipment onboard in consistency with the 4th IMO GHG study. Finally, OPEX per tanker's class were retrieved from the Ship Operating Costs report by Grainer (2017), and the annual operating days per year were estimated from data gathered from previous studies at DTU and combined with the data published in the 4th GHG study. All the parameters above and the resulting equations of our model are derived statistically, are indicative, and can be easily be tailored to a specific ship case study.

7. Results

Fig. 8 presents the results of the model on the optimal laden and ballast speed for an indicative study case of a VLCC sailing from Ras Tanura to Singapore for different levy scenarios. The different colors on the graphs represent the different spot rate scenarios as described in Section 5. As anticipated, an increasing level of the levy shown on the x-axis leads to a corresponding decrease in both speeds, meaning that the value of sailing faster, fulfilling more round trips per year, is counterbalanced by a more significant increase in the overall operating costs for the ship including the levy.

Furthermore, it is evident that at higher spot rate conditions, a significantly higher level of the levy is required to counterbalance the profit incentive to sail faster, serving the purpose of handling more cargo. On the other hand, at a lower spot rate, ships are already slow steaming, and the margin for achieving a significant speed and thus CO_2 emissions reductions is much lower. In that case, a lower level of the levy is required to achieve emissions reductions in the short term, and the final revenues generated would be lower as compared to a higher levy scenario.

Fig. 9 shows the results of our analysis on the final equal throughput CO_2 emissions of a VLCC sailing from Ras Tanura to Singapore for different levy scenarios. Equal throughput CO_2 emissions consider the appropriate shipping capacity that needs to be added to the relevant fleet in order to compensate for the annual throughput loss due to speed reduction. This is true both at an individual ship or company level and at a fleet level. As examined by Cariou (2011), the vessel's reduced speed would force the industry to incorporate more vessels into the global fleet for maintaining throughput, an action that would actually lead to additional CO_2 emissions. Due to the non-linearity of the fuel consumption function, these additional emissions would be lower than the emissions reduction due to speed reduction. The calculation of the throughput adjustment factor under the BAU – no levy – scenario lets us consider the additional ships needed, to content the annual BAU throughput and cover the demand.

In Table 5 as "equal vessel throughput" we estimated the number of ships that will be needed in each scenario to retain the BAU throughput. This is defined as the ratio of the annual throughput of a single vessel without a levy, divided by the corresponding annual throughput with a levy, both throughputs expressed in MT miles. This ratio is at least 1.00 as the denominator of the ratio has the numerator as its upper bound due to the speed reduction induced by the levy. Then annual CO_2 emissions need to be multiplied by this ratio to reflect the addition of shipping capacity in order to maintain throughput, and this is shown in Fig. 9. Needless to say, the availability of such additional tanker capacity in the short-term is not guaranteed, especially at a global fleet level. If such capacity is not available, this would result in higher freight rates and/or reduced freight throughput.

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[3] https://unctadstat.unctad.org/EN/

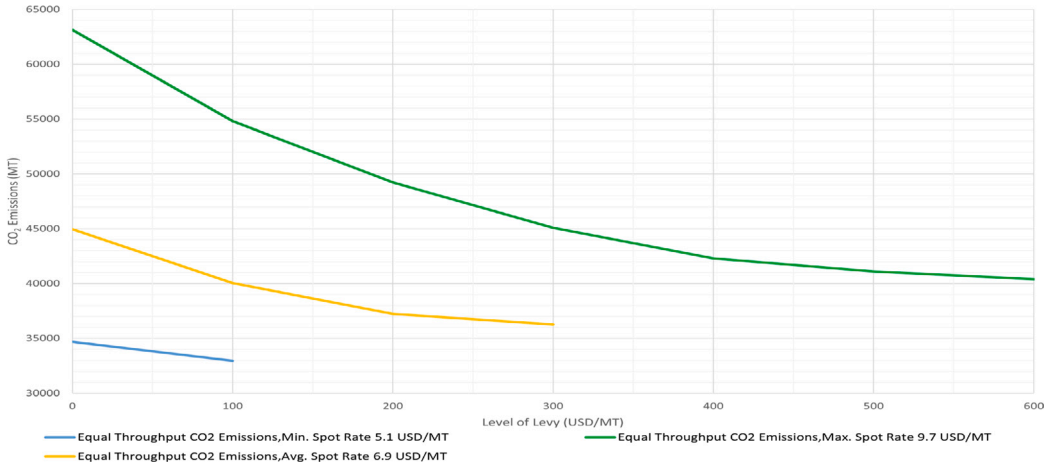

Fig. 9. Equal Throughput CO_2 emissions for different levy and spot rate scenarios for a VLCC sailing from Ras Tanura to Singapore.

Tables 5 and 6 summarize our results for the tanker sizes and routes under scope. The potentials in emissions reductions vary and are highly dependent on the level of the spot rate applicable in the market. Results range from 1% to 43% of reduction among all the scenarios. It is seen that in case of prosperous market period the levy should be higher in order to achieve the same level of emissions reductions, as opposed to a depressed market condition. Our model's outputs also indicate that a 50% reduction does not appear achievable for the tanker segment, at least by inducing slower speeds. Energy saving technological devices and alternative fuels can be the long-term impacts of a bunker levy and are essential elements of the Initial IMO strategy, however their consideration is outside the scope of this paper.

In the above runs, the use of a baseline bunker price of BP_0= 403.4 USD/MT for HFO (and 615 USD/MT for MGO) causes no loss of generality in the results. If a different baseline bunker price BP_1 ($\neq BP_0$) is used, no new model runs are necessary, everything else being equal. The speed and emissions results for a baseline bunker price of BP_0 and a levy l_0 are the same as the corresponding results for a baseline bunker price of BP_1 and a levy $l_1 = l_0 + \Delta BP$, where $\Delta BP = BP_0 - BP_1$.

Overall, any implementation of an MBM for shipping should consider all the major market parameters interfering with the industry. The effectiveness of any monetary regulation that aims to incentivize the polluters by increasing the cost of consuming depends on the overall balance between total revenues and costs. Therefore, the shipping operators' final response will be determined by the overall market conditions. Policymakers could utilize these figures to foresee the short-term impacts of a levy on speed for different scenarios (vessel size and route combinations).

8. Discussion

Currently, at both the IMO and the EU, the pressure for introducing an MBM for shipping is increasing, as such regulation can assist in accelerating the industry's transition towards decarbonization. The results of the 4th IMO GHG Study (Faber et al., 2020) showed that emissions from shipping continue to rise and a solid regulatory intervention is needed for delivering the targets set out in the Paris Climate Accord. At the EU level, the impending inclusion of shipping in the EU ETS is likely to cause speed reduction and thus a corresponding reduction of CO_2 emissions — but only on the legs in which the scheme is applied. The measure's efficiency depends on the price of carbon allowances which is determined by the EU carbon market. The possible side-effects of the measure on international trade are currently unclear and may include flow reconfiguration and reverse modal shifts to land-based modes (see Psaraftis et al., 2021, Cariou et al., 2021 and Wang et al., 2021 for some insights).

At the IMO level, the Marshall Islands and Solomon Islands proposal for a carbon levy of approximately 300 USD/MT of fossil fuel (IMO, 2021a) has been introduced for discussion at the IMO in the fall of 2021. Other stakeholders, such as the commodity trader Trafigura, which is not represented at the IMO, have suggested a higher levy of 900 USD/MT (Trafigura, 2020). The fate of these proposals is at this time unclear, and the IMO process is slow mainly due to political reasons. This paper has shown the appropriate range of levy as a function of freight rate conditions and has calculated the expected range of CO_2 emissions reductions for the tanker sector, should levies like these be applied.

The way a possible global bunker levy might be applied is subject to discussion. Variants may entail which ship sizes would be subject to the levy, whether and to what ships there should be exemptions, the timing of the levy, and others (see Psaraftis and Lagouvardou (2019) for a discussion). Our view is that a uniform levy should be preferred, as exemptions and possible differentiation of the levy with respect to ship type, size and route would likely create distortions and would be difficult to enforce.

A question that might arise is whether policy makers should be dynamically adjusting the level of the levy, as a function of freight rate conditions, for instance have a higher levy in case the market is high or a lower levy in case the market is low. This is obviously up to the policy makers to decide, however a levy that is being adjusted time-wise in such a fashion would not provide price stability and would be difficult to administer. None of the levy proposals to the IMO has suggested a dynamically adjusted levy and any such variant may in many ways resemble the carbon price fluctuations of an ETS and would carry with it all the problems of price uncertainty and administrative burden associated with an ETS.

Table 5
Emissions reductions for various oil tanker sizes, routes and spot rates.

Ship Class	Route	Spot Rate Scenario (USD/MT)	Levy for Max. Emissions Reduction (USD/MT)	Equal Vessel Throughput	Emissions Reduction
VLCC	Ras Tanura–Singapore	Min:5.10	100	1.04	−5%
		Avg:6.88	300	1.14	−19%
		Max:9.73	600	1.27	−36%
	Ras Tanura–Chiba	Min:8.65	200	1.07	−9%
		Avg:12.25	400	1.22	−26%
		Max:16.98	700	1.37	−42%
	Port Harcourt–Shanghai	Min:13.68	200	1.11	−13%
		Avg:18.44	400	1.25	−28%
		Max:24.85	700	1.40	−42%
	Offshore Bonny–LOOP	Min:7.52	200	1.20	−6%
		Avg:11.20	400	1.21	−26%
		Max:18.08	900	1.38	−43%
Suezmax	Forcados–Philadelphia	Min:8.90	100	1.01	−1%
		Avg:13.01	200	1.10	−16%
		Max:16.98	400	1.21	−29%
	Novorossiysk–Rotterdam	Min:9.54	200	1.08	−13%
		Avg:12.75	400	1.18	−27%
		Max:16.32	600	1.26	−38%
	Sidi Kerir–Lavera	Min:4.77	200	1.04	−8%
		Avg: 6.34	400	1.11	−21%
		Max:8.05	600	1.16	−31%
Aframax	Primorsk–Wilhemshaven	Min:5.54	200	1.05	−10%
		Avg:7.04	400	1.11	−23%
		Max:8.57	500	1.15	−32%
	Curacao–Houston	Min:6.72	200	1.07	−14%
		Avg:9.40	500	1.16	−31%
		Max:12.20	700	1.23	−42%
	Mina Al Ahmadi–Singapore	Min:10.76	200	1.07	−11%
		Avg:14.63	400	1.18	−29%
		Max:19.06	600	1.27	−41%
Panamax	Ras Tanura–Yokohama	Min:17.60	400	1.12	−23%
		Avg:25.62	800	1.19	−38%
		Max:31.41	1000	1.24	−42%
	Aruba–New York	Min:8.41	700	1.12	−29%
		Avg:10.96	1000	1.16	−39%
		Max:13.51	1300	1.18	−43%
	Antwerp–Houston	Min:17.10	600	1.15	−31%
		Avg:22.98	900	1.21	−42%
		Max:27.78	1200	1.25	−43%

Table 6
Emissions reductions ranges for various oil tanker sizes and spot rates.

Ship Class	Spot Rate	Levy Range (USD/MT)	Emissions Reduction Range
VLCC	Low	100–200	5%–13%
	Avg.	300–400	19%–28%
	High	600–900	36%–43%
Suezmax	Low	100–200	1%–8%
	Avg.	200–400	16%–21%
	High	400–600	29%–38%
Aframax	Low	100–200	10%–14%
	Avg.	400–500	23%–31%
	High	400–600	32%–42%
Panamax	Low	400–700	23%–31%
	Avg.	800–1000	38%–42%
	High	1000–1300	42%–43%

A potential limitation of our approach is that spot rates were considered as an exogenous variable in our analysis, and no attempt was made to link them with supply and demand for shipping, which was out of the scope of this paper. We note that any slow down of segments of the fleet would shrink the shipping capacity supply curve and might lead to increases in freight rates, the level of which would depend on the interaction between shipping supply and demand. In periods of shipping capacity oversupply, such freight rate increases are not expected to be significant. However, in case the fleet is in low supply and/or demand is high for whatever reason, freight rates are expected to increase. In the discussion on the potential impacts of MBMs, the state of the shipping markets is, therefore, an important parameter that needs to be factored in. Any period of fleet overcapacity as we move towards 2050 will make MBMs less effective in the short-term.

We reiterate a recommendation made in Gkonis and Psaraftis (2012) which seems more relevant now. If laden leg ship speeds are not constrained by charter party speed clauses (which is the scenario examined in this paper), lower CO_2 emissions are likely to occur. Conversely, a charter party agreement specifying a prescribed speed, explicitly or implicitly, might entail significant costs, both in terms of additional fuel (which is a private cost matter) and in terms of additional CO_2 emissions (which is a cost to society). In the IMO and EU discussions on GHGs/MBMs, regulatory action to prevent such clauses in charter party agreements could very well be worth looking into as a policy alternative.

9. Conclusions

This paper aimed to evaluate the effectiveness of a bunker levy in achieving GHG emissions reductions in the shot term by inducing speed reduction. Our study found that based on historical data, the implementation of a significant levy on bunker fuels will result in speed reduction, the extent of which is highly dependent on the level of the overall ratio of freight rates to the fuel price at the time of enforcement. However, we also found that additional and better AIS data is necessary to further support this result.

On the examined range of CO_2 emissions reductions achieved for different levy scenarios this study concluded that there is a potential of up to 43% of reductions but the upper bound was realized only under high spot rate scenarios. In low spot rate cases, the emissions reduction potential is much lower since ships are already sailing slow during these periods of recession, and any potential levy would only have marginal effects. During poor market conditions, a very high levy may also lead to competition disruptions among the different transportation sectors, leading to further carbon leakage. Because of the increased financial burden that the demand will not absorb, other transportation sectors may become more cost competitive. The results depend on the tanker segment and the route under scope. Similar results may apply to any ship type, even though individual numerical results may vary.

Our results indicate that the short-term speed reduction derived from implementing a levy regardless of the spot rate is not enough as an operational measure to reach the 50% reduction target of the IMO. However, a levy on bunker fuel would serve the industry both ways, by decreasing the overall GHG emissions in the short term and by supporting R&D and the development of alternative fuels and energy saving technologies in the long term. This solution would offer price certainty to the operators and time to adjust their practices and strategies to adapt their business.

As this paper was being finalized, the IMO discussion on mid-term measures, including MBMs, was set to continue in mid 2022. In the final analysis, meeting the IMO goals will ultimately entail a basket of technological, operational, and market based measures, and the role of the regulators will be to choose the most appropriate such measures and induce stakeholders to move towards implementing them.

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