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Bunker levy schemes for greenhouse gas (GHG) emission reduction in international shipping

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A B S T R A C T

A fuel levy is one of the market-based measures (MBMs) currently under consideration at the International Maritime Organization. MBMs have been proposed to improve the energy efficiency of the shipping sector and reduce its emissions. This paper analyses the economic and environmental implications of two types of levy on shipping bunker fuels by means of an analytical model built on the cobweb theorem. A unit-tax per ton of fuel and an *ad-valorem* tax, enforced as a percentage of fuel prices, are examined. In both cases, a speed and fuel-consumption reduction equivalent to an improvement in the energy efficiency of the sector would be expected as a result of the regulation enforcement. The speed reduction in the unit-tax case depends on fuel prices and the tax amount, whereas in the *ad-valorem* case it relies upon the enforced tax percentage.

Both schemes lead to industry profit decline, the extent of which depend on the structure of the levy and market conditions. Since there is concern that the costs resulting from the policy will be passed from shipping companies to their customers along the supply chain, the paper dwells on how the costs arising from the enforcement of the levy will be actually allocated between ship-owners and operators, and cargo-owners. In a market characterised by high freight rates and with no or limited excess capacity, a higher percentage of the total tax amount is transferred from ship-owners to shippers. In case of a recession the opposite happens.

1. Introduction

Emissions produced by the maritime transport industry are increasing rapidly (IMO, 2014), despite recently introduced environmental regulation i.e. the enforcement of Emission Control Areas (ECAs), the Energy Environmental Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). Those initiatives proved to have significant unexpected consequences. ECAs, for example, in addition to tackling NO_x and SO_x may lead to an increase in CO_2-emissions (Fagerholt et al., 2015; Doudnikoff and Lacoste, 2014; Gilbert, 2014). Anderson and Bows (2012) argue that the EEDI is not far-reaching enough to reduce shipping emissions at the levels necessary to meet climate-change targets. Besides the index could have been more effective in reducing emissions if only had it been applicable also to older ships (Miola et al., 2011). As far as the SEEMP is concerned, crucial gaps have been identified in the formulation of the regulation compared to other best-practice certifications (i.e. ISO 50001 and ISM) in terms of how companies should interpret and implement its provisions and hence this measure may not contribute to the enhancement of shipping companieś energy management system (Johnson et al., 2013). Although it is clear that additional policy interventions to influence and improve the industry environmental performance are necessary, it is, however, imperative that their environmental and economic

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consequences are beforehand well-understood. And this should happen soon if the industry is to make a fair contribution to tackling climate change.

The international character of maritime transport and its primarily business-to-business nature are some of the obstacles to the development of effective environmental regulation in shipping. By comparison with other transportation sectors, emission abatement policies are already in place in various countries under different forms i.e. fuel or engine taxation. Environmental taxes indeed resulted in exhaust gases mitigation in the car sector (e.g. Rogan et al., 2011; Hennessy and Tol, 2011) and in the aviation industry (e.g. Swedavia, 2015; Flughafen Zürich, 2010).

Only in July 2009 did the MEPC 59 ask from Member States, Associate Members and observer organisations to submit their MBM proposals for further consideration. MBMs are considered an effective GHG emission mitigation solution by the IMO. Their aim is primarily twofold, namely:

- to provide economic incentives to shipping companies to invest in more environmentally-friendly technologies and to increase operational efficiency, and
- to offer a mechanisms to offset emissions out of the shipping industry (IMO, 2016).

Most proposals can be related to the two schemes currently still under examination: an Emission Trading Scheme (ETS) and a bunker levy. An ETS requires the shipping sector to satisfy a GHG emission reduction cap that has been set *a priori*, making it illegal for ships to operate beyond the allocated emissions and without offsetting (Psaraftis, 2012). The scheme would favour more energy-efficient operators, and penalise progressively the less environmentally friendly. Notwithstanding the intuitive appeal of the scheme and the undeniable advantages of extending to shipping an already existing framework, the actual implementation of an ETS encompassing the shipping sector remains controversial. A critical issue is whether to develop an open ETS or a maritime specific ETS (METS), with the advantage of a better control of financial transactions within the maritime sector. The consequences of the schemes are also controversial. Wang et al. (2015) expect in both cases a speed, workload and fuel-consumption decrease. As far as the inclusion of the shipping industry in an open ETS is concerned, it may lead to a higher supply reduction in the bulk sector than in the liner shipping industry (Luo, 2013). The economic impact of an ETS on the World GDP will be likely small, with the exception of developing countries, where it will depend on the country's trade balance and the relative importance of the shipping industry (Anger et al., 2013). Regarding the introduction of a METS, Koesler et al. (2015) argue that it will have the capability to operate as an effective measure, having as a major advantage the low additionally required administrative effort.

One of the measures proposed by the Member States, Associate Members and observer organisations is the enforcement of a bunker levy scheme, in other words a tax raised on fuel consumption on-board of vessels. The bunker levy proposal is linked to the establishment of an International Greenhouse Gas Contribution Fund that would collect a so-called *contribution* on all ships over 400GT differentiating according to the type of fuel used proportional to the fuel consumed. It is worth mentioning that in the proposal the term *contribution* is consistently used referring to the amounts due by owners and operators instead of the terms *tax* or *levy*, as IMO's responsibility is limited to the prevention of marine pollution from vessels and does not include tax-raising. The essential meaning of the *contribution*, semantics aside, is the same.

The enforcement of a tax in shipping at a global scale—there is nothing of the like at the moment in any other industry—raises questions of effectiveness and is controversial in terms of the actual arrangements necessary for the tax collection (IMO, 2007; Psaraftis, 2012). Notwithstanding the intuitive appeal of such measure for policy-makers, its application is based on assumptions on the costs for the industry and society at large, which are highly uncertain. Given the far-reaching implications of such policy, it is disquieting that to date the efforts among researchers and policy-makers to clarify some of the uncertainty associated with a bunker levy scheme have been rather limited.

The academic literature on the bunker levy so far is scant. Psaraftis (2012) argued that a levy would provide price certainty, as the extra costs resulting from the scheme will be known beforehand, thus enabling ship-owners to act proactively by investing in new technologies. Additionally, Kapetanis et al. (2014) claim that a levy is the easiest measure to be enforced and the most suitable to the maritime industry, but highlight that some degree of flexibility regarding the payable amount is needed. Amounts should depend on market conditions, as deviations from optimal outcomes are possible as a result of modal shift towards less environmentally-friendly transport modes. Another study (Lee et al. 2013) explored the global economic impact of a bunker levy in the liner shipping industry in terms of profitability, sector competitiveness and implications for GDP. The study observes an increase in competition among liner companies operating in long haul routes, an attraction of more demand in short distance routes and 0.02% loss in China's GDP. As a result they suggest that the levy scheme should be differentiated according to the shipping costs on every trade route.

An area of study is the comparison of the levy environmental effectiveness with other pieces of regulation aimed at GHG emission reduction. Cariou and Cheaitou (2012) argued that in terms of resource allocations a globally enforced bunker levy is the preferable option compared to a Europe-wide speed limit. Despite the positive attitude of the research community towards a levy scheme, the industry's opinion is more divided with some stakeholders expressing outright concerns towards such measure (Giziakis and Christodoulou, 2012). The costs of the levy would eventually not be absorbed by the shipping sector but just passed along the supply chain (Global Shippers' Forum, 2012) with virtually no impact on the energy efficiency profile of the industry and higher transportation costs. Should this be the case, the levy scheme would be inadequate as a MBM to foster energy efficiency improvements in the industry. This debate makes the exploration of the economic implications of a bunker levy particularly timely. A rigorous investigation of the significance of the claim that the levy would be passed along the supply chain requires the use of tax incidence and cost pass-through theory, which are an interconnected and important area of research in economics. A first economic analysis pointing towards this direction can be found in the report of vivideconomics (2010) prepared for the Expert Group on MBMs of the

IMO. It focuses on the economic impact of a generic MBM through a 10% bunker price increase on specific shipping routes and product markets in terms of price, market share and demand changes as well as cost pass-through rate derivation. The present manuscript differs from the report in terms of methods used, as its focus is on the determination of a general economic explanation of the consequences of alternative taxation schemes.

Literature on tax incidence has focused on how tax policies affect the distribution of economic welfare (Kotlikoff and Summers, 1987). Given the possibility of passing through taxes by those who they target to other segments of society, tax incidence theory has attracted considerable attention and has been applied in different industries at macroeconomic level (e.g. Tokarick, 2006; Besley and Rosen, 1999), on specific industries (e.g. soft drinks in Bonnet and Réquillart, 2013; tobacco, Hanson and Sullivan, 2009; and Harding et al. 2012) and in transport (e.g. gasoline tax in Agostini and Jiménez, 2015; Doyle and Samphantharak, 2008).

Cost pass-through refers to the price change of a product offered in a business industry resulting from its cost change. A thorough description of this theory framework is presented in the report of RBB Economics (2014) prepared for UK's Office of Fair Trading. The report describes the cost pass-through theory in case of an industry-wide or idiosyncratic cost change, or when differentiated supply and demand conditions are applied and for cases of alternative competition forms. In economics, tax incidence and cost pass-through are closely linked through the supply and demand equilibrium concepts and aim at identifying in the case of a tax change how the levy will be allocated between consumers and producers.

This paper is one of the first contributions to focus on the economic and environmental effects of a bunker levy scheme in an international context; applying also cost-pass through theory via a dynamic economic model that captures the market interactions of the industry. The paper examines and benchmarks two different forms of levy that are studied with specific reference to the international shipping industry: a unit-tax per ton of fuel and an *ad-valorem* tax, enforced as a percentage on fuel prices. These forms of schemes had been included in the discussion at MEPC level at IMO; either as a fixed cost on fuel costs, found in the feasibility study and impact assessment report of the expert group appointed by the agency (IMO, 2010) or as a percentage increase of bunker expenses found in the previously mentioned report of vivideconomics (2010). Nevertheless, since 2013 when the discussions came to a halt at MEPC 65 no significant progress has been made. The objective of this study is twofold. Firstly, the outcome of the bunker levy in terms of costs and environmental effects is investigated, with particular focus on speed optimization and energy efficiency improvements at the industry level. Secondly, the study will investigate what portion of the levy will be passed from the ship-owners along the supply chain, as this is perceived to be one of the critical issues in the debate on the implementation of the MBMs (Global Shippers' Forum, 2012), given the importance that a potential cost transfer has on the effectiveness of the policy in improving environmental efficiency.

One of the reasons, in fact, for which these forms of indirect taxation are preferred to a tax as a percentage of freight rates or of profit, is that the levy affects the shipping company fuel costs, and as such should provide an incentive to increase energy efficiency. Hence, these schemes are aligned with the "polluter pays" principle endorsed also by the IMO. The impact of the levy on technical or operational efficiency, however, depends on whether these costs are transparent and can be easily forecasted by the owner or operator. In the case of a unit tax the costs are fixed and can be estimated on the basis of fuel consumption in previous years, in contrast costs associate with an *ad-valorem* tax are more uncertain, as the excised amount varies depending on bunker prices.

This issue is relevant in particular from a policy-making perspective. The general framework provided in the study on how the bunker levy is potentially transferred from the shipping industry to cargo-owners, which takes into consideration the price elasticities of supply and demand, offers a tool to assess the effectiveness of the scheme. The prevailing market conditions in the shipping industry turn out to be a determinant factor. From an industry perspective, the study offers useful insights for owners in terms of what operational and technical measures are best suited to minimise the negative effects of the scheme. Particular attention is devoted in the paper to optimal speed for both schemes, whose levels depend on the levy scheme structure implemented among other factors.

The study provides an academic contribution to the current knowledge on transport policy in multiple ways. Firstly, notwithstanding the importance of maritime transport for the global economy, and the significance of any form of regulation that could potentially increase the costs of moving cargo by ship, studies on MBMs in shipping have been few and far between. Secondly, the existing quantitative studies concerning MBMs in shipping have focused primarily on Emission Trading Schemes (ETS) (e.g. Wang et al., 2015) while levy schemes have been examined chiefly using qualitative methods. Thirdly, the paper provides an important contribution in identifying the issues that need to be further investigated so that the impacts of MBMs can be adequately assessed. Finally the contents of the paper are useful also for ship-owners and operators and the industry by and large.

The paper is structured in four sections. This introduction outlines the main problem associated with the inadequacy of the existing emission mitigation measures and policies, mentioning the need for supplementary actions. This section also discusses the concept of market-based measures, its application in other transport industries and the existing literature proposing its use in international shipping. In Section 2 an economic model encompassing the main characteristics of international deep-sea maritime transport and different forms of levy schemes is constructed. In Section 3, the economic and environmental implications of the policy are presented. Finally Section 4 concludes the study by providing a summary of the main findings, its limitation and recommendations for further research topics that need to be addressed.

2. A bunker levy market equilibrium model

2.1. A shipping market equilibrium model

In order to investigate the impact of a bunker levy on the shipping sector a theoretical equilibrium model of supply and demand is proposed. The model is based on the cobweb theorem proposed by Kaldor (1934) and uses a different approach from majority of

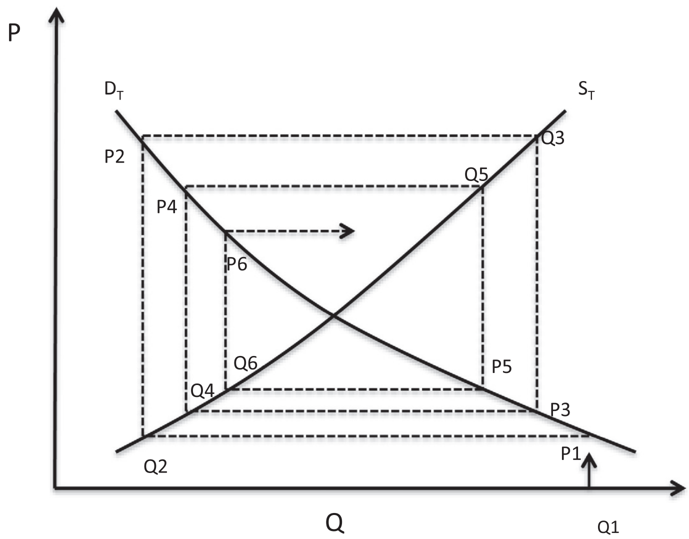

Fig. 1. Cobweb model; .
Source: Ezekiel (1938)

demand and supply models used in shipping that are typically empirical (e.g. Tinbergen, 1959; Beenstock and Vergottis, 1993; Lewis and Koopmans, 1939; Strandeness, 1984; and Tsolakis, 2005). These studies, beyond their empirical value, are useful in understanding the relations among economic variables in shipping. Additional literature reviews that are valuable for understanding the maritime industry can be found in Haralambides et al. (2004), where a model of new building and second-hand markets behaviour is provided and in Alizadeh and Talley (2010), where the authors present the microeconomic determinants of freight rates and contract times of the bulk shipping sector with the use of a simultaneous equations method.

A recent study of Luo et al. (2009), which presents an empirical econometric model of container shipping demand and fleet capacity for the analysis of freight rates, is particularly relevant to this paper since it also applies the cobweb theorem. This is one of the most recent studies and the only one that makes use of this theorem in shipping. The cobweb theorem explains prices, supply and demand fluctuations in an industry, where the time-lag between demand and supply is critical. Three conditions need to be satisfied to apply the cobweb theorem (Ezekiel, 1938). The first condition is that production is based on the producer response to prices in perfect competition and also that production decisions taken by a producer individually do not affect the market. The second condition refers to the fact that available supply is fixed when prices are determined. The last condition is that, in order for the scale of production to be changed, a full period is required.

Before introducing the model developed in this paper, a description of the functioning of the cobweb model (see Fig. 1) and of the shipping markets is expedient (Kaldor 1934). In the first period a greater supply Q1 is available intersecting the demand curve at its responding price P1. At the second period a reduced supply Q2 is identified due to the previous observed price value, that consequently intersects the demand curve at a higher value P2. The higher price will lead to an increase in the supply at Q3 that will then intersect the demand curve at a lower price value at P3 at period 3. This decreased price will result in a decrease in the supply value in the next period 4, Q4, which will then drive the price up at P4. The same procedure will continue for the next phases. The price sensitivity of supply and demand is the determining factor for the behaviour of the industry's models. When distortions in supply and demand appear, the industry will enter in a new cobweb model.

The cobweb model needs to be adapted to the shipping industry that consists of four interacting markets: the freight market, the shipbuilding market, the sale and purchase market and the demolition market. The freight market, the main source of revenue, plays the most important role in ship-owners decisions. The demolition market acts also as a revenue source during economically tough times when ship-owners may decide to demolish inefficient and older vessels. Sometimes it can act as a relief instrument against industry's overcapacity. However, in real life industry specific cases can be found when ship-owners hold on to older vessels in the hope of a market economic upturn. In the sales and purchase market the money transactions neither change the fleet capacity nor the industry owned cash amount. Money is spent by the ship-owners to purchase new vessels in the new building market. In the case where demand exceeds the supply of the industry and needs to be covered a freight rate rise is observed, leading consequently to a revenue increase. Subsequently, ship-owners are willing to pay higher prices for second-hand vessels. However, when prices are extremely high new buildings are preferred. When the new ships are delivered, capacity is added into the sector, which drives freight rates to a decrease. In the case that ship-owners cannot remain active due to the financial downturn, they either sell or demolish ships seeking for revenues so as to manage to stay in business (Grammenos, 2010; Stopford, 2009).

In the model proposed in this paper, interactions in the sale and purchase market will be ignored since they do not affect the capacity of the world fleet. Likewise, the new building market will not be modelled because it does not have a direct impact on the determination of freight rates. On the contrary, new building prices are dependent on freight rates, following a pattern similar to that of the determination of second-hand vessel prices (Stopford, 2009). Demand (X) in the model is considered exogenous similarly to other studies e.g. Luo et al. (2009) and Taylor (1976). Moreover, since the time factor is of vital importance for the application of the cobweb theorem it is appropriate to take into account the ship delivery time θ of a new order. Usually θ ranges between one to two years but in some situations i.e. during the last boom of 2007, delivery time may rise significantly. The market equilibrium is expressed by the equation: $Q_S^{FR} = Q_D^{FR}$; whereas Q_S^{FR} stands for the quantity that is being supplied and Q_D^{FR} for the quantity that is being demanded.

Furthermore, the model assumes that supply of shipping is influenced by the following factors:

- World fleet capacity Z (dwt).
- New orders delivery N (dwt).
- Industrial Profit = Π (US$).

The bunker levy in included in the model as T (US$) and it affects the supply of shipping services through the freight rates, indicated with P. Thus freight rates can be expressed as a function:

$$P = g(\Pi, T|Z, N, X)$$

We follow the assumption made in Luo et al. (2009), based on the idea that high freight rates imply a high turnover for the business, and the total new order for ships for period t (a year) is stated as

$$N_{t=}n \times \Pi_t \quad (1)$$

where n is the average profit proportion accounting for new vessel purchase. Profit is calculated as

$$\Pi_t = P_t X_t - TC_t \quad (2)$$

where P_t are freight rates at time t (expressed in US$ per ton), and X_t is demand at time t (expressed in tons of cargo carried). TC stands for total costs and can be expressed by

$$TC_t = (OC_t + F_t)\Psi_t \quad (3)$$

Total costs consists of two parts. The first is OC_t that accounts for the vessel operating costs at time t, expressed in US$, such as crew costs and repairs, are fixed; considered in the model as exogenous as in other studies i.e. Hsu and Hsieh (2007). The second element is voyage costs, that following Wang et al. (2015) can be expressed as:

$$F_t = \rho_t f_t \lambda_t S_t^3 \quad (4)$$

Without loss of generality, Eq. (4) does not include all voyage costs, just only fuel costs[1] as they account for the highest percentage of voyage costs (Psaraftis and Kontovas, 2013).

ρ_t accounts for operating time at sea (in hours), f_t is fuel price (US$/ton), taken as exogenous since freight rates or fleet capacity do not have an influence on their price, λ_t is the coefficient regarding the energy efficiency of a ship and S_t (knots) is average speed, all at time t.

The total costs per ship are multiplied by Ψ_t that refers to the number of ships required in order to satisfy demand and can be defined as

$$\Psi_t = \frac{X_t * d_t}{H_t * S_t * \rho_t} \quad (5)$$

where d_t, is the route distance (nautical miles) and H_t is ship's average capacity (tons).

The change in industrial fleet capacity is defined as:

$$\Delta Z_t = Z_t - Z_{t-1} = N_{t-\theta} \quad (6)$$

Hence, combining the Eqs. (1-6), the world fleet dynamic can be expressed as:

$$\Delta Z_t = n(P_{t-\theta} X_{t-\theta} - (OC_{t-\theta} - F_{t-\theta})\Psi_{t-\theta}) \quad (7)$$

Following Luo et al. (2009) and applying the cobweb theorem, the freight rate change in international shipping can be expressed as:

$$\Delta P_t = \delta * (\Delta X_t - \varphi * \Delta Z_t) \quad (8)$$

where $\Delta P_t = P_t - P_{t-1}$, ΔX_t is the change in cargo transported at an industrial level, ΔZ is the change in fleet capacity, $\delta > 0$ refers to the freight adjustment factor on the basis of demand and supply alterations and $\varphi > 0$ (constant) is the average fleet capacity utilisation rate.

[1] It should be mentioned that in practice the party who bears the fuel expenses is not always the ship-owner, as often it is the operator or the charterer who are contractually obliged to cover bunker costs, as in the case of the so called *time charter* or *bareboat charter*. The case in which the ship-owner bears the costs of fuel is referred to as *voyage charter*. In this paper we assume, without loss of generality that the economic agent is the one responsible for operational decisions, and this could be the ship-owner, the operator or the charterer. We will refer in general to the ship-owner, unless it is critical for the discussion to distinguish among the various roles, for example when analysing the longer-term consequences of a levy scheme.

2.2. The unit-tax scenario

The cobweb model is modified to include a bunker levy parameter. The first levy that is introduced is in the form of a unit tax. With the introduction of a tax the equations for profit, fleet and freight rates need to be modified. In order to distinguish the unit tax from the *ad-valorem* tax, they will be indicated respectively as *TP* and *VP* and collectively as *T*.

The profit equation is modified to include the unit tax as

$$\Pi_t^u = P_t X_t - (OC_t + \rho_t (f_t + TP)\lambda S_t^3) * \Psi_t \tag{9}$$

Eq. (7) after inclusion of the unit tax becomes:

$$\Delta Z_t = n(P_{t-\theta} X_{t-\theta} - (OC_{t-\theta} + \rho_{t-\theta}(f_{t-\theta} + TP)\lambda S_{t-\theta}^3)\Psi_{t-\theta}) \tag{10}$$

By substitution of ΔZ_t in Eq. (8), the change in freight rates is then:

$$\begin{aligned}\Delta P_t &= \delta(\Delta X_t - \varphi \Delta Z_t) = \\ &= \delta \Delta X_t - \delta \varphi n(P_{t-\theta} X_{t-\theta} - (OC_{t-\theta} + \rho_{t-\theta}(f_{t-\theta} + TP)\lambda S_{t-\theta}^3)\Psi_{t-\theta})\end{aligned} \tag{11}$$

2.3. The ad-valorem scenario

In the case of an *ad-valorem* tax, where VP is expressed as a percentage on fuel prices, in a similar way to the unit-tax case, Eqs. (2), (7) and (8) become:

$$\Pi_t^v = P_t X_t - (OC_t + \rho_t (f_t (1 + VP))\lambda S_t^3) * \Psi_t \tag{12}$$

$$\Delta Z_t = n(P_{t-\theta} X_{t-\theta} - (OC_{t-\theta} + \rho_{t-\theta} f_{t-\theta}(1 + VP)\lambda S_{t-\theta}^3)\Psi_{t-\theta}) \tag{13}$$

$$\begin{aligned}\Delta P_t &= \delta(\Delta X_t - \varphi \Delta Z_t) = \\ &= \delta \Delta X_t - \delta \varphi n(P_{t-\theta} X_{t-\theta} - (OC_{t-\theta} + \rho_{t-\theta} f_{t-\theta}(1 + VP)\lambda S_{t-\theta}^3)\Psi_{t-\theta})\end{aligned} \tag{14}$$

3. Economic implications

3.1. Speed optimisation and industry's energy efficiency

The objective of a ship-owner is to maximise profits.[2] Under this assumption, it is possible to determine the values of freight rates, *P*, and supply, *Z*, at the period *t*. Through the cobweb theorem and the model developed in the previous section, it can be shown that these variables are dependent on their values at periods $t - 1$ and $t - \theta$. Since the proposed levy schemes are imposed at period t, the values for P_{t-1}, Z_{t-1}, $P_{t-\theta}$ and $Z_{t-\theta}$ are already known in the model as they account for the previous observed years, and can be assumed in the model as exogenous. Until time *t* no tax had been included. However, the tax will influence the level of freight rates and supply from period $t + 1$ onwards.

The sector's profit with the inclusion of a bunker levy can be calculated following Eq. (2) for every levy scheme as

$$\Pi_t^u = P_t * X_t - (OC_t + \rho_t * (f_t + TP) * \lambda_t * S_t^3)) * \frac{X_t * d_t}{H_t * S_t * \rho_t} \quad \text{for the unit-tax scenario, and} \tag{15}$$

$$\Pi_t^v = P_t * X_t - (OC_t + \rho_t * (f_t * (1 + VP) * \lambda_t * S_t^3)) * \frac{X_t * d_t}{H_t * S_t * \rho_t} \quad \text{for the } ad\text{-}valorem \text{ scenario.} \tag{16}$$

Applying the first order conditions in the profit maximisation equations[3] w.r.t. speed for the first and second levy schemes respectively result in:

$$\frac{d\Pi_t^u}{dS} = -\frac{X_t * d_t}{H_t * \rho_t} * \left(2 * \rho_t (f_t + TP) * \lambda_t * S_t - \frac{OC_t}{S_t^2}\right) \tag{17}$$

$$\frac{d\Pi_t^v}{dS} = -\frac{X_t * d_t}{H_t * \rho_t} * \left(2 * \rho_t * f_t (1 + VP) * \lambda_t * S_t - \frac{OC_t}{S_t^2}\right) \tag{18}$$

Since the traffic volumes, the quantity transported (demand), fuel prices, operating costs, freight rates, fuel consumption and speed

[2] This research paper will not include the asset play case, which can occasionally result in high financial gains for ship-owners, but will focus only on the revenues gained from the trade activity. The logic behind this assumption is that industry's fleet capacity during an asset play situation does not experience any change, remaining consequently constant.

[3] In the simplified industry organisation assumed in the paper, if companies maximise their profits then the industry profit will be also maximised. The industrial profit cannot be maximised if any company does not maximise its profits. To every individual maximum profit there is a corresponding optimal speed; hence, the summation of the maximum profits corresponds to an average of individual optimal speeds.

have non-negative values, based on Eqs. (17) and (18) the optimal speed ($\widetilde{S}$) and optimal fuel consumption of international shipping after a levy enforcement can be calculated as:

$$\widetilde{S} = \sqrt[3]{\frac{OC_t}{2*\rho_t*\lambda_t*(\text{ f+ TP})}}, \quad \text{and} \tag{19.1}$$

$$\widetilde{S} = \sqrt[3]{\frac{OC}{2*\rho_t*\lambda_t*f_t(1+VP)}} \tag{19.2}$$

$$\widetilde{FC_t} = \rho_t*\lambda_t*S_t^3\frac{\text{X}*\text{d}}{\text{H}*\widetilde{S}*\rho} = \frac{\sqrt[3]{\left(\frac{OC_t}{2*\rho_t*\lambda_t*(\text{f+TP})}\right)^2}}{H_t}*\lambda_t*X_t*d_t, \quad \text{and} \tag{20.1}$$

$$\widetilde{FC_t} = \frac{\sqrt[3]{\left(\frac{OC_t}{2*\rho_t*\lambda_t*f_t(1+\text{TP})}\right)^2}}{H_t}*\lambda_t*X_t*d_t \tag{20.2}$$

It can be seen that the extra costs from the levies are imposed and added to the total fuel costs. It is expedient to calculate the derivatives of speed and fuel consumption with respect to fuel costs and the industry energy efficiency for both cases respectively.

$$\frac{d\widetilde{S}}{d(f+TP)} = -\frac{1}{3}\sqrt[3]{\frac{OC_t}{2*\rho_t*\lambda_t*(f_t+\text{TP})^4}}, \quad \text{and} \tag{19.3}$$

$$\frac{d\widetilde{S}}{d(f+f*VP)} = -\frac{1}{3}\sqrt[3]{\frac{OC_t}{2*\rho_t*\lambda_t*(f_t+f_t*\text{ VP}))^4}} \tag{20.3}$$

$$\frac{d\widetilde{S}}{d\lambda} = -\frac{1}{3}\sqrt[3]{\frac{OC_t}{2*\rho_t(f_t+TP)*\lambda_t^4}}, \quad \text{and} \tag{19.4}$$

$$\frac{d\widetilde{S}}{d\lambda} = -\frac{1}{3}\sqrt[3]{\frac{OC_t}{2*\rho_t(f_t+f_t*VP)*\lambda_t^4}} \tag{20.4}$$

The meaning of the above derivatives can be easily interpreted. Because of the negative sign of Eqs. (19.3) and (20.3) and the non-negativity of the parameters, when fuel prices rise, as a result of the enforcement of a levy scheme, or the industry vessel efficiency decreases, ship-operators will consequently sail at a lower speed in order to minimise the additional costs. This speed reduction will have an effect on fuel consumption, which will consequently decline. By taking the ratios of fuel consumption with the inclusion of the levy ($\widetilde{FC_t}$) to fuel consumption without the levy imposition (FC_t), presented in Eqs. (21.1) and (21.2), a levy will result in a new (lower) optimal speed, and fuel consumption will decline.

$$\frac{\widetilde{FC}}{FC} = \frac{\lambda_t*X_t*d_t*\frac{\sqrt[3]{\left(\frac{OC_t}{2*\rho_t*\lambda_t*(f_t+\text{TP})}\right)^2}}{H_t}}{\frac{\rho_t*\lambda_t*S_t^3*X_t*d_t}{H_t*\rho_t*S_t}} = \sqrt[3]{\left(\frac{f_t}{f_t+TP}\right)^2} < 1, \quad \text{for the unit tax}, \quad \text{and} \tag{21.1}$$

$$\frac{\widetilde{FC}}{FC} = \sqrt[3]{\left(\frac{1}{1+VP}\right)^2} < 1, \text{ for the } \textit{ad–valorem tax} \tag{21.2}$$

Another noteworthy aspect relates to the role that energy efficiency is bound to play within the shipping industry as alternative fuels and forms of propulsion become more common. Should fuel consumption decrease because of improved energy efficiency, the impact of the levy would not need to be accommodated by speed reduction to maintain profit levels. This is an important issue since the model does not account for technology change, which is one of the main policy drivers behind the introduction of a levy. It should also be considered that the effectiveness of speed reduction as a response to a levy is limited, especially in view of the slow steaming observed in the last decade resulting from poor market conditions. Hence, it is critical that policies complement the introduction of a levy in order to overcome barriers to the uptake of environmentally- friendly novel technologies (Acciaro et al., 2013).

A possible solution is linking the deployment of a bunker levy scheme to financial aid to shipping companies to incentivise the investing in new technologies. A successful example in this respect is Norwegian *NO_x Fund (*Høibye, 2011). The NO_x Fund was established after the enforcement of a national NO_x tax in Norway. The structure of the tax allowed shipping firms to be exempted under an agreement with the Ministry of the Environment, but contribute an equivalent fee proportional to their emissions to a fund. The collected amounts are then redistributed to shipping companies as financial support for the deployment of environmentally-friendly technologies (up to 80% of the total investment). The Norwegian approach contributed to the 12% reduction of the country's total NO_x emissions between 2008 and 2011, and has fostered the rapid uptake of new environmentally-friendly ships (Høibye, 2011).

In the same context of eco-friendliness enhancement through policy implementation, the different level of a levy impact on the

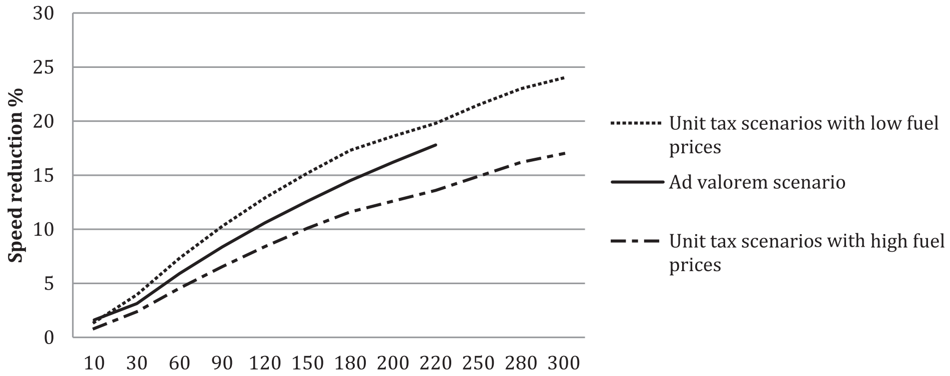

Fig. 2. Speed reduction with differentiated imposed tax values.

shipping industry's agents should be addressed. For the case of voyage charter, it is expected that the level of incentive would be higher compared to the case of time charter, as the costs have to be borne by the ship-owner (IMO, 2010). The expectation of an energy efficiency premium in time charter rates is complex due to the existence of market failure; empirical evidence of the bulk sector shows that during normal market conditions only 14–27% of bunker savings are revealed in the increased rates while greener ships are penalised during market booms (Adland et al., 2017). In order to overcome this market failure Adland et al. (2017) suggest the implementation of obligatory and standardised systems aiming at the collection and distribution of ships' energy efficiency related data as a potential policy solution.

As far as the decrease in optimal speed is concerned, it is useful to discuss the factors that affect speed change, and how profits in the sector are affected. The latter is discussed in Section 3.2. While as far as the former is concerned, if we indicate the percentage change in speed with M, we have:

$$M = \frac{\widetilde{S}-S}{S} = \sqrt[3]{\frac{f_t}{f_t + TP}}-1 \quad \text{for the unit-tax scheme, and} \tag{22.1}$$

$$M' = \frac{\widetilde{S}-S}{S} = \sqrt[3]{\frac{1}{1 + VP}}-1 \quad \text{for the } \textit{ad–valorem} \text{ scheme} \tag{22.2}$$

A speed reduction resulting from a tax, will be inversely related to the size of the tax, independently from the type of tax. However, the speed change necessary to compensate the tax, will depend, in the case of a unit-tax per ton of bunker, also on the fuel prices. This is one of the main differences between the two schemes and the implications of such difference can be observed in Fig. 2. Assuming a bunker prices of $234 per ton (the level of bunker prices observed in October 2015) and $400 per ton, different tax rates are applied and examined (see Tables 1–3). For the unit-tax scenario charges of $10, $30, $60, $90, $120, $150, $180, $200, $220, $250, $280 and $300 per ton of bunker fuel are imposed. As far as the *ad-valorem* scenario is concerned, charges of 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% per ton of bunker are chosen.

In the case of a low fuel price value, a unit-tax scheme will elicit a higher speed reduction than the *ad-valorem* one. Inversely, when fuel prices are at high level, then the *ad-valorem* tax will prompt a higher speed decrease. It should be noted that this is counterintuitive, as it would be expected that higher speed reductions would be associated with higher fuel prices. This is not always the case as it can be shown that, with realistic fuel prices, other things being equal, a unit-tax scenario with low value fuel prices can result in a higher speed reduction than a unit tax with high value fuel prices.

Table 1
Speed reduction: unit-tax scheme with low fuel prices.

TP ($/ton)	M (%)
10	1.39
30	3.94
60	7.33
90	10.28
120	12.9
150	15.2
180	17.3
200	18.6
220	19.8
250	21.5
280	23
300	24

Table 2
Speed reduction: unit-tax scheme with high fuel prices.

TP ($/ton)	M (%)
10	0.82
30	2.38
60	4.55
90	6.54
120	8.4
150	10.1
180	11.6
200	12.6
220	13.6
250	14.9
280	16.2
300	17

Table 3
Speed reduction: *ad-valorem* scheme.

VP (%)	M (%)
5	1.61
10	3.13
20	5.9
30	8.37
40	10.6
50	12.6
60	14.5
70	16.2
80	17.8

3.2. Profit differentiation

Having found the optimal speed and fuel consumption for both cases respectively, it is feasible to examine the influence of the proposed levy schemes on the industry profit. The profit-maximising values of $\widetilde{S_t}$ and $\widetilde{FC_t}$ are substituted in the previously obtained profit function. The derivatives with respect to the tax for both levy scenarios are:

$$\frac{d\widetilde{\Pi_t}}{dTP} = -\left[\frac{X_t*d_t*\sqrt[3]{OC_t^2}*\sqrt[3]{2*\rho_t*\lambda_t}}{3*H_t*\rho_t*\sqrt[3]{(f_t+TP)^2}} + \frac{2*\rho_t*\lambda_t*X_t*d_t*\sqrt[3]{OC_t}}{3*H_t*\rho_t*\sqrt[3]{2*\rho_t*\lambda_t}*\sqrt[3]{f_t+TP}}\right] \text{ for the unit tax,} \tag{23.1}$$

$$\frac{d\widetilde{\Pi_t'}}{dVP} = -\left[\frac{X_t*d_t*\sqrt[3]{OC^2}*\sqrt[3]{2*\rho_t*\lambda_t*f_t}}{3*H_t*\rho_t*\sqrt[3]{(1+VP)^2}} + \frac{f_t*\rho_t*\lambda_t*\sqrt[3]{OC_t^2}*X_t*d_t}{3*H_t*\rho_t*\sqrt[3]{(2*\rho_t*\lambda_t*f_t)^2}*\sqrt[3]{(1+VP)^2}}\right] \text{ for the } ad{-}valorem. \tag{23.2}$$

As it was to be expected, both derivatives are negative. This can be interpreted as a levy market effect, and the result is that a tax will result in the reduction of profits. It is useful to examine how the industry profits decrease for both levy scheme scenarios. The change in profit can be indicated with *N,* that is

$$N = \frac{\widetilde{\Pi_t} - \Pi_t}{\Pi_t} = \frac{OC_t*d_t*(S^{-1}-\widetilde{S}^{-1}) + d_t*\lambda_t*\rho_t*(f_t*S_t^2-(f_t+TP)*\widetilde{S_t^2})}{H_t*\rho_t*P_t - OC_t*d_t*S^{-1} - f_t*\rho_t*\lambda_t*S_t^2*d_t} = \\ = \frac{A + d_t*\lambda_t*\rho_t*(f_t*S_t^2-(f_t+TP)*\widetilde{S_t^2})}{B} \quad \text{for the unit-tax scenario,} \tag{24.1}$$

$$N' = \frac{\widetilde{\Pi_t'} - \Pi_t}{\Pi_t} = \frac{OC_t*d_t*(S^{-1}-\widetilde{\widetilde{S}}^{-1}) + d_t*\lambda_t*\rho_t*f_t*(S_t^2-(1+VP)*\widetilde{S_t^2})}{H_t*\rho_t*P_t - OC_t*d_t*S^{-1} - f_t*\rho_t*\lambda_t*S_t^2*d_t} = \\ = \frac{A + d_t*\lambda_t*\rho_t*f_t*(S_t^2-(1+VP)*\widetilde{S_t^2})}{B} \quad \text{for the } ad{-}valorem \text{ scenario} \tag{24.2}$$

Fig. 3 illustrates the changes in profit for the two scenarios. The data used are for the year 2007, presented in Wang et al. (2015):

- Sailing speed prior the tax is S = 14 kts,
- ship size used H = 49,000 tons,
- ρ = 6480 h,
- demand of the industry X = 4100 million tons,

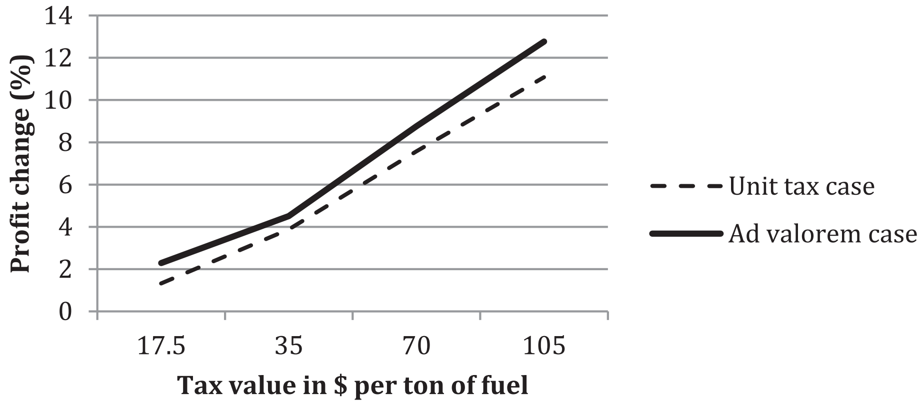

Fig. 3. Profit reduction in both levy schemes.

- average voyage distance d = 9036 nms,
- f = 350 $/ton,
- ship's efficiency $\lambda = 0.0012$,
- P = 48$/ton and
- annual operation costs of ship OC = $\$1.51 \times 10^7$.

An *ad-valorem* scheme would lead to a higher profit loss in the shipping industry.

3.3. Levy cost allocation

One of the main purposes of this analysis is to investigate how costs are allocated between ship-owners and operators, and cargo-owners i.e. who actually bears the burden of the tax. To this end, the cost pass-through theory is useful, but the estimation of the allocation share requires a set of assumptions on the price elasticity of supply and demand. The price elasticity of supply and demand can be expressed as:

$$E_s = \frac{\%\Delta Z}{\%\Delta P} = \frac{\%change\ in\ quantity\ supplied}{\%change\ in\ price} \quad \text{and} \quad E_d = \frac{\%\Delta W}{\%\Delta P} = \frac{\%change\ in\ quantity\ demanded}{\%change\ in\ price}$$

It can be assumed, without loss of generality, that at the periods t-1 and t-θ the levy schemes is in place, so to illustrate the consequences of Eqs. (25) and (26) on the amount of tax that will be borne by the shipper and ship-owner or ship-operator at period t. The fraction of the levy costs, ξ, can be expressed as:

$$\xi = E_d/(E_d + E_s) = (\Delta X_t * Z_{t-1})/(\Delta Z_t * X_{t-1} + \Delta X_t * Z_{t-1}) \tag{25}$$

In the same way, the fraction of the levy costs borne by the consumer, ζ, in our case the shipper is presented as:

$$\zeta = E_s/(E_d + E_s) = (\Delta Z_t * X_{t-1})/(\Delta Z_t * X_{t-1} + \Delta X_t * Z_{t-1}) \tag{26}$$

The enforcement of a levy scheme in the shipping industry is similar to the case of industry-wide cost pass-through since the change in the costs associated with a tax has an effect on all firms involved (i.e. the shipping companies). It is important to highlight that the extent of the cost change passed to consumers (i.e. the shippers) by the firms does not need to be uniform but can be different from consumer to consumer and depends on the price elasticity of demand.

At this point it is interesting to observe how ξ and ζ vary depending on market conditions. Therefore, as an example, the periods 2012–2013 and 2006–2007 are used. The approximate values of the data are taken from UNCTAD Review of Maritime Transport (UNCTAD, 2014, 2013, 2007). If the levy schemes had been enforced in those periods the values of the fleet capacity and freight rates would have been different. The data is provided for illustration purposes only in order to assess the potential impact of market conditions on the values of ξ and ζ. In the first period Z_{2013} = 725″010″000 dwt, Z_{2012} = 684″600″000 dwt, X_{2012} = 4″322″580″645 tons and ΔX = 2″377″419″355 tons (UNCTAD, 2014; UNCTAD, 2013). Inserting this data into (25) and (26), it can be calculated that ξ_{2013} = 90.3% and ζ_{2013} = 9.7%. The extra costs from a theoretical tax had to be absorbed mainly by the carriers.

Since the values of ξ and ζ depend entirely on the price elasticity of supply and demand and taking into consideration over-capacity and low freight rates, the result, albeit unexpected, can be explained. In the second example for the years 2006 and 2007, when X_{2007} = 2 billion tons, X_{2006} = 1.8 billion tons, Z_{2007} = 361″928″000 dwt and Z_{2006} = 338″107″000 dwt (UNCTAD, 2007). The results show that ζ_{2007} = 52%, so that the highest portion of tax will to be borne by the shippers. Hence, when the market conditions are favourable for the shipping industry, with buoyant demand and high freight rates, a higher percentage of the tax costs can be passed to the shippers.

4. Conclusion

The research paper focused on the economic implications from the introduction of a bunker levy scheme in international shipping. Two alternative forms of tax, a unit and an *ad-valorem*, were examined and benchmarked. A dynamic economic model is used for the analysis, which differs from previous ones as it accounts for the inclusion of a tax parameter. The model is constructed making use of the cobweb theorem, which has been deployed previously in shipping only for forecasting.

The model provides the basis for the benchmark of the two levy schemes. In both cases, the levy results in additional costs that compound with fuel expenses. Speed optimization will result in a speed reduction and can compensate partial profit losses. The benefits of such strategy, however, are limited, as speed cannot be reduced indefinitely. This will require in the medium term to find other ways to improve the energy efficiency profile of the sector by investing in new environmentally-friendly technologies, which is one of the stated aims of MBM. The analysis presented in this paper contributes to the identification of the factors that determine a speed change. In the case of the unit-tax scenario, the change varies depending on the values of fuel price and the fixed amount of tax. In the *ad-valorem* case, on the other hand, it relies upon the percentage set up as the tax scheme and fuel prices have no influence on the cost increase resulting from the introduction of the tax. The analysis proved a profit decline associated to the levy scheme enforcement in both cases.

As far as the question whether the enforced tax costs will be just passed along the supply chain, the research provides the framework of how the tax amount is allocated in the industry. Since the price elasticity of supply and demand is the determinant factor for determining what percentage of the tax will be passed along the supply chain or will be absorbed by the beneficial ship operators, when the market conditions are favourable for ship-owners, with high freight rates and limited overcapacity, a higher portion of the extra costs accruing from the introduction of the levy scheme, can be transferred to the cargo beneficiaries.

This paper is one of the first attempts to illustrate the implications of the introduction of a levy scheme in the shipping sector. Given the importance of the shipping sector for the global economy and the urgency of climate action, the analysis of the impacts of MBM is particularly pressing. A bunker levy scheme can act as an incentive for investments in environmentally-friendly technologies. Nevertheless, in order to mitigate the negative impacts on ship-owners, especially in poor markets, MBM should be linked to a reimbursement scheme through the provision of financial aid so as to increase the adoption of new technologies. This is particularly urgent as the saving opportunities obtainable through speed reduction are quickly exhausted. The existing Norwegian *NOx Fund*, described in Section 4.1, appears for example a useful and viable proposition. The IMO should take into consideration that part of the resources collected though MBMs should be destined to foster research and ease the financial burden on shipping companies that proactively invest in green technologies. Associating the enhancement of the shipping industry eco-friendliness and the reduction of GHG emissions to the provision of (financial) support to the companies for greener technologies is vital for achieving a policy outcome that does not jeopardise the wellbeing of the international shipping sector.

Despite the study contributions, several limitations can be identified. The first limitation is that demand is considered as exogenous and inelastic. This assumption holds mainly for deep-sea shipping and not for short sea shipping (SSS), where competition with other transport modes exists. Given that this manuscript is one of the first efforts in analysing a bunker levy scheme, topics for further examination still remain open and need to be addressed. The economic effects on SSS and the possibility of a modal shift to alternative competing transportation modes should also be explored; a challenging issue as a bunker levy scheme may hinder its promotion and exploitation. The implications of MBM on world trade (Luo, 2013), the risk of modal shift (Psaraftis and Kontovas, 2010), and the impact on the profitability of the maritime industry, as illustrated in this paper, are reasons important enough to motivate further research. The enforcement of a bunker levy scheme will lead to dissimilar effects on shipping networks and industry segments, as the supply and demand interactions are dependent on trade routes. The possible solution for the industry of decreasing further sailing speed so as to cope with the extra costs may challenge the operational and logistics activities especially in the container shipping sector. Hence, further areas for further research could include: (a) implications in global supply chains i.e. just-in-time delivery problems, alterations in shipping networks, change in trade patterns (b) economic implications in other maritime sectors, (c) examination of other forms of environmental tax schemes. These and other areas need to be looked at now if academic research is to provide guidance for an informed policy debate, in the absence of which, inertia and political interests are bound to prevail, to the detriment of the Planet, the shipping industry and society by and large.

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