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# Modeling the Impacts of Alternative Emission Trading Schemes on International Shipping

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**ABSTRACT:** Various market-based measures have been proposed to reduce CO2 emissions from international shipping. One promising mechanism under consideration is the Emission Trading Scheme (ETS). This study analyzes and benchmarks the economic implications of two alternative ETS mechanisms, namely, an open ETS compared to a Maritime only ETS (METS). The analytical solutions and model calibration results allow us to quantify the impacts of alternative ETS schemes on the container shipping sector and the dry bulk shipping sector. It is found that an ETS, whether open or maritime only, will decrease shipping speed, carrier outputs and fuel consumption for both the container and dry bulk sectors, even in the presence of a "wind-fall" profit to shipping companies. Under an open ETS, the dry bulk sector will suffer from a higher proportional reduction in output than the container sector, and will thus sell more emission permits or purchase fewer permits. Under an METS, container carriers will buy emission permits from the dry bulk side. In addition, under an METS the degree of competition within one sector will have spill-over effects on the other sector. Specifically, when the sector that sells (buys) permits is more collusive (competitive), the equilibrium permit price will rise. This study provides a framework for identifying the moderating effects of market structure and competition between firms on emission reduction schemes, and emphasizes the importance of understanding the differential impacts of ETS schemes on individual sectors within an industry when considering alternative policies.

**KEY WORDS:** ***Shipping industry, open and closed Emission Trading Scheme (ETS), carbon emission***

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# 1. Introduction and background

Market-based measures (MBM) are cost-effective policy instruments that can provide industrial organizations with strong incentives to use up-to-date technological, operational and managerial practices in emission reduction (Buhaug et al., 2009; European Commission, 2013a). One of the most promising alternatives in MBM is the Emission Trading Scheme (ETS) (Kageson, 2007; Miola et al., 2011). In the US, the trading programme of $SO_2$ has been very successful (Klaassen, 1996). Since its initial launch in 2005, the European Union (EU) ETS has become by far the largest ETS in the world, now having around 12,000 installations and representing 45% of EU emissions of $CO_2$ (Grubb, 2006; Wrake et al., 2012). However, there has been rather limited progress in emission reduction from international shipping (European Commission, 2013b). Whereas numerous political and institutional factors could be blamed for such slow progress, certain important issues remain to be studied and evaluated concerning the ETS itself.

An ETS involving the shipping industry can be either "open" or "closed". In an open system, shipping companies can trade emission permits with other industries (e.g., electricity generation, manufacturing or agriculture), whereas in a closed ETS (or Maritime ETS, METS) shipping companies can only trade among themselves. In theory, the scale of an open/broader ETS is larger because it allows permits to be traded with other industries, which makes the ETS system more transparent and the allocation of permits among different industries more efficient. In METS, an appropriate emission cap is hard to set up, because international shipping is growing fast, and associated $CO_2$ emissions are estimated with a high degree of uncertainty (Kageson, 2007). The cap has to be generous, since an excessively tight cap is very hard to change at a later stage, which could bring excessive pressure and cost to the shipping industry and may even limit the possibility of international trade (Luo, 2013). Such considerations would favor the choice of an open ETS. However, an METS also has its own advantages. It is more feasible to implement from a policy, institutional and economic perspective (Schmidt et al., 2004; Bosi & Ellis, 2005); it is relatively easy to target a given sector rather than the entire economy; and building technical capacity and data collecting are more manageable at a sectoral level. In summary, both broad and sector-specific mechanisms are being considered by regulators and government agencies, and no definite decision has yet been made.[1]

In addition, these two types of ETS can have different impacts on the shipping industry. The shipping industry is not composed of homogeneous carriers. Different types of cargo are carried in specialized ships that have differing operational costs and energy efficiency. The market structure and conduct of companies also differ among the various shipping sectors. For example, it is generally perceived that, on average, in comparison with container ships, dry bulk ships are older, less expensive and less energy efficient. Bulk cargos tend to have a lower value per ton, and thus such ships generally sail slower compared to container ships. In terms of market structure, the container shipping market tends to be less competitive, due to high market concentration, and the existence of liner conferences and alliances (Cullinane & Khanna, 2000; Song & Panayides, 2002). These features will make each sector respond to the ETS differently, resulting in different impacts on international trade (Song & Panayides, 2008; 2012a; 2012b; Lam, 2011; 2013; Lam & Van de Voorde, 2011; Cristea et al., 2013). Despite this, few published studies have investigated such an important issue.

Apparently, any proposed mechanism needs to be endorsed or supported by major stake-holders. Therefore, without a good assessment and clear understanding of the possible consequences, the different sectors of the shipping industry may not be able to reach a consensus, which could well delay the implementation of the proposed emission reduction schemes. Bosi and Ellis (2005) emphasized the need to carry out *ex ante* studies prior to the

[1] For detailed and updated information related to mechanism design and choice, see for example UNFCCC's reports at http://unfccc.int/bodies/awg-lca/items/4488.php and OECD/IRA's reports at http://www.oecd.org/env/cc/scaling-upmarketmechanisms.htm

formation of a mechanism, and *ex post* studies to monitor and evaluate subsequent progress. However, previous studies on emission reduction in international shipping have mostly focused on operations and technologies (Eyring et al., 2005; DNV , 2010), emission volume and cost simulation (Wang et al., 2007; Buhaug et al., 2009; Eide et al., 2009; 2011; Liao et al., 2010), or emission permit allocation mechanisms (Kling & Zhao, 2000; Haites, 2009; Hepburn et al., 2006). Although a few studies have provided comprehensive evaluations of alternative policy instruments on emission reduction (CE Delft, Germanischer Lloyd, MARINTEK and Det Norske Veritas, 2006; Kageson, 2007; Eide et al., 2011), they have not analyzed the economic implications for the international shipping industry as a result of the ETS, nor the differential impacts on the various shipping sectors. The inception of the EU ETS in 2005 motivated a number of economic studies, such as on the carbon cost pass-through ratio and its effects on end products' prices (Sijm et al., 2006; Chen et al., 2008; Kim et al., 2010), the effects on firms' profitability and stock prices (Smale et al., 2006; Oberndorfer, 2009; Demailly & Quirion, 2006; Veith et al., 2009; Mo et al., 2012), alternative emission permit allocation methods (Bode, 2006) and geographic and country differences (Knight, 2011; Viguier et al., 2006). Although these studies provide rich insights into the EU ETS, they have mostly focused on one single sector (e.g., the power generation industry) without investigating the implications of an open vs. a closed scheme. The implications of differences across sectors within an industry have not been considered either. Therefore, these studies cannot provide direct guidance on the impacts of an ETS on the international shipping industry.

In this paper, we investigate and benchmark two different ETS mechanisms for the international shipping industry, namely, an open ETS in comparison to a closed maritime only scheme (METS). The analytical solutions and model calibration results allow us to evaluate the effectiveness of ETSs in achieving emission reduction objectives. More importantly, the impacts of alternative ETSs on different shipping sectors, such as the container shipping sector and the dry bulk shipping sector, are identified and benchmarked. It is found that an ETS, whether open or closed, will decrease ship speed, carrier output and fuel consumption in both container and bulk shipping sectors, even in the presence of a "wind-fall" profit to shipping firms, and that the level of reduction has a positive relationship with the emission permit price. Shipping volume reduction due to an ETS will be more severe when shipping costs are higher, which gives shipping firms strong incentives to improve fuel efficiency. Under the METS, the emission reduction objective is predetermined and will not be altered by the trade of permits. An increase in permit price will have the same effect on shipping volume, shipping speed and fuel consumption as the open ETS. However, market structure under the METS will have more significant impacts than in the case of an open ETS. The degree of competition/collusiveness of one shipping sector (e.g. container or dry bulk) will only affect the sector's own performance in an open ETS, but will affect other sectors in the case of an METS. Such an externality is due to the fact that competitiveness in each sector will affect market equilibrium, and thus the price of emission permits prevailing in both sectors. Our model calibration results confirm and quantify such effects, and predict that the container sector will buy emission permits from the dry bulk side under an METS.

This paper is organized as follows. Section 2 sets up the basic model and solves the market equilibrium without any ETS, which is then used as a benchmark case. Section 3 solves the equilibrium under an open ETS. Section 4 considers an METS for the container and bulk shipping sectors. Section 5 calibrates the analytical model with industry data to obtain practical managerial and policy insights. Section 6 provides concluding remarks and proposes future research.

# 2. Economic model and benchmark case

This study models the impacts of possible ETS schemes on two representative sectors in the international shipping industry, namely the dry bulk sector and the container shipping sector. The former has the largest volume shipped, whereas the latter has the fastest growth rate (UNCTAD, 2011). Our modeling results can hold if multiple sectors are considered. Focusing on two sectors, however, will make the model mathematically tractable, and thus a clear intuition can be obtained with closed-form solutions.

We consider the case where there are $N_1(N_2)$ carriers providing homogenous container (bulk) shipping services in a particular shipping market (global or regional). The annual demands for container shipping and bulk shipping are independent from each other (not substitutable), which can be modeled with the following demand functions:

(1) $$P_r = a_r - b_r \sum_{i=1}^{N_r} q_{r,i} \qquad i = 1, \dots N_r \text{ and } N_r \geq 1$$

where $q_{r,i}$ is carrier *i's* annual output ($r = 1$ for container carrier; $r = 2$ for bulk carrier), while $P_r$ is the market price of shipping in sector *r*. Define $t_{r,i}$ as the time for carrier $i$ to complete a voyage. If the average distance per voyage is $D_r$, and the average speed of a ship is $S_{r,i}$, we have $t_{r,i} = D_r/S_{r,i}$. Assume that the number of days at sea in a year is $\rho$ and that the ship capacity is $U_r$, then the total quantity of cargo that one ship can carry is $U_r \frac{\rho}{t_{r,i}} = U_r \frac{\rho S_{r,i}}{D_r}$. From this, the total number of ships required for carrier $i$ to move $q_{r,i}$ units of cargo can be written as $\frac{q_{r,i}}{U_r \frac{\rho S_{r,i}}{D_r}} = \frac{q_{r,i} D_r}{U_r \rho S_{r,i}}$.

Generally, a carrier's cost for one ship can be specified as the sum of the voyage cost and a fixed cost $\gamma_{r,i}$, which does not change with speed. $\gamma_{r,i}$ may include operating costs, periodic maintenance, cargo-handling costs, and capital costs (Stopford, 2009, p.225). It is assumed that $\gamma_r$ is exogenous, and is hereafter referred to as ship operation cost for short.

Since the predominant part of a voyage cost is fuel cost, following Psaraftis et al. (2009) and Corbett et al. (2009) (Psaraftis et al., 2009; Corbett et al., 2009), fuel cost can be expressed as a cubic function of ship speed as specified in equation (2)[2], where $\lambda_r$ is a coefficient representing a ship's energy efficiency and $\eta$ is fuel price.

(2) $$f_{r,i} = \rho \eta \lambda_r S_{r,i}^3$$

The lower the value of $\lambda_r$ means the less fuel that is consumed by a ship for the same speed, hence the higher the energy efficiency. Assuming that a carrier maximizes its profit by choosing the shipping volume and cruising speed, the objective function of a carrier can be written as:

(3) $$Max_{q_{r,i}, S_{r,i}} \pi_{r,i} = P_r q_{r,i} - (f_{r,i} + \gamma_r) \frac{q_{r,i} D_r}{U_r S_{r,i} \, \rho}$$

where $f_{r,i}$+$\gamma_r$ is the total cost per ship. The first order conditions (FOCs) are:

(4.1) $$\frac{\partial \pi_{r,i}}{\partial q_{r,i}} = a_r - 2b_r q_{r,i} - b_r \sum_{j \neq i}^{N_r} q_{r,j} - b_r q_{r,i} \sum_{j \neq i}^{N_r} \frac{\partial q_{r,j}}{\partial q_{r,i}} - \frac{D_r}{U_r S_{r,i} \, \rho} \left[ \rho \eta \lambda_r S_{r,i}^3 + \gamma_r \right] = 0$$

(4.2) $$\frac{\partial \pi_{r,i}}{\partial S_{r,i}} = - \frac{q_{r,i} D_r}{U_r \, \rho} \left[ 2 \rho \eta \lambda_r S_{r,i} - \frac{\gamma_r}{S_{r,i}^2} \right] = 0$$

[2] It is recognized that the cubic law between speed and fuel consumption only applies to a ship's main engine, whereas auxiliary engine fuel consumption is independent of speed (Corbett et al., 2009). Thus, fuel costs for an auxiliary engine can be categorized into the fixed cost of a ship's operation cost $\gamma_r$.

Referring to Brander and Zhang (1990; 1993), Fu et al. (2006), Oum and Fu (2007), Basso and Zhang (2008), we introduce a conduct parameter $\nu_{ri,j} = \sum_{j \neq i}^{N_r} \frac{\partial q_{r,j}}{\partial q_{r,i}}$, $-1 \leq \nu_{ri,j} \leq N_r - 1$ into FOC (4.1), so that our model is applicable to a spectrum of competition games. This conduct parameter measures the level of competitiveness in the market. The more negative the $\nu_{ri,j}$ is, the higher the level of competition is. Specifically, $\nu_{ri,j} = 0$ corresponds to the Cournot competition; $\nu_{ri,j} = -1$ corresponds to the Bertrand competition; $\nu_{ri,j} = N_r - 1$ corresponds to perfect collusion among firms to maximize joint profit. It can be checked that the Hessian matrix for the profit maximization problem in equation (3) is negative definite, which satisfies the second order condition for profit maximization.

Considering non-trivial cases only, we restrict the study to non-negative traffic volumes. Assuming firms are identical in each sector, it is sufficient to use $q_r$ and $S_r$ to denote the quantity and shipping speed of each company, and use $\nu_r$ for the competitiveness. Then the equilibrium speed and quantity for a carrier can be solved:

(5.1) $$\tilde{S}_r = \sqrt[3]{\frac{\gamma_r}{2\rho\eta\lambda_r}} > 0$$

(5.2) $$\tilde{q}_r = \frac{2a_r U_r \rho - 3D_r \sqrt[3]{2\rho\eta\lambda_r \gamma_r^2}}{2U_r \rho b_r[(N_r+1)+\nu_r]}$$

By (5.1), the optimal speed is a function of ship operation cost and energy efficiency, as well as fuel price. It is clear that ship speed is lower if a ship has a lower operation cost, lower efficiency (higher $\lambda_r$), or higher fuel price.

The fuel consumption volume at equilibrium can be obtained as

(5.3) $$\tilde{F}_r = \rho\lambda_r \tilde{S}_r^3 \frac{\tilde{q}_r D_r}{U_r \rho \tilde{S}_r} = \frac{\sqrt[3]{2\rho\lambda_r \gamma_r^2} D_r (2a_r U_r \rho - 3D_r \sqrt[3]{2\rho\eta\lambda_r \gamma_r^2})}{4\sqrt[3]{\eta^2} U_r^2 \rho^2 b_r[(N_r+1)+\nu_r]}$$

The non-negativity of shipping quantity $\tilde{q}_r$ and fuel consumption $\tilde{F}_r$ implies that $2a_r U_r \rho > 3D_r \sqrt[3]{2\rho\eta\lambda_r \gamma_r^2}$. In addition, the following comparative statics results can be obtained:

(6) $\frac{\partial \tilde{q}_r}{\partial \eta} < 0, \frac{\partial \tilde{q}_r}{\partial \lambda_r} < 0, \frac{\partial \tilde{q}_r}{\partial D_r} < 0, \frac{\partial \tilde{q}_r}{\partial \nu_r} < 0, \frac{\partial \tilde{q}_r}{\partial U_r} > 0, \frac{\partial \tilde{q}_r}{\partial \gamma_r} < 0; \frac{\partial \tilde{S}_r}{\partial \eta} < 0, \frac{\partial \tilde{S}_r}{\partial \lambda_r} < 0, \frac{\partial \tilde{S}_r}{\partial \gamma_r} > 0; \frac{\partial \tilde{F}_r}{\partial \eta} < 0, \frac{\partial \tilde{F}_r}{\partial \nu_r} < 0.$

Interpretations of the above comparative statics are straightforward: When fuel price increases or the fuel efficiency is lower, carriers will reduce ship speed to save fuel, leading to lower total fuel consumption and traffic outputs. When ship operation cost increases, carriers increase ship speed to reduce the number of ships needed. When carriers are more collusive, they will reduce their deployed capacities so as to raise market price, which allows them to achieve higher profits — but shipping volume will be reduced.

# 3. An open ETS

Under an open ETS, carriers can trade emission permits with other industries. As international shipping only accounts for 2.7% of global $CO_2$ emissions, including it in an open scheme such as the EU ETS should have minimal effect on the price of emission permits. Therefore, the price of an emission permit ($\chi$) is assumed to be exogenous. In such a case, the ETS is equivalent to a uniform charge on emission, which can be a positive tax/charge (if carriers buy emission permits) or a negative subsidy (if carriers sell emission permits). Since there is a definite relationship between fuel consumption and gas emission, the ETS is equivalent to a tax/subsidy on fuel consumption. Reflecting common practices observed under existing ETSs, it is assumed that each carrier is pre-allocated a quota of free emission which is $\theta\ (0 < \theta < 100\%)$ percentage of its fuel consumption prior to the ETS. The profit maximization problem of a firm is therefore defined as follows:

(7) $$Max_{q_{r,i},S_{r,i}}\pi_{r,i} = P_r q_{r,i} - (f_{r,i} + \gamma_r)\frac{q_{r,i}D_r}{U_r S_{r,i}\,\rho} - \chi[\rho\lambda_r S_{r,i}^3 \frac{q_{r,i}D_r}{U_r S_{r,i}\,\rho} - \theta\tilde{F}_r]$$

Since the container and bulk shipping sectors trade emission permits under the open ETS separately, the solutions for these two sectors are independent. The outcomes of trade are determined by emission permit price $\chi$ and the target of emission reduction percentage $(1-\theta)$. The FOCs for maximization problem (7) are:

(8.1) $$\frac{\partial\pi_{r,i}}{\partial q_{r,i}} = a_r - 2b_r q_{r,i} - b_r\sum_{j\neq i}^{N_r} q_{r,j} - b_r q_{r,i}\sum_{j\neq i}^{N_r}\frac{\partial q_{r,j}}{\partial q_{r,i}} - \frac{D_r}{U_r S_{r,i}\,\rho}[\rho(\eta+\chi)\lambda_r S_{r,i}^3 + \gamma_r] = 0$$

(8.2) $$\frac{\partial\pi_{r,i}}{\partial S_{r,i}} = -\frac{q_{r,i}}{U_r\,\rho/D_r}\left[2\,\rho(\eta+\chi)\lambda_r S_{r,i} - \frac{\gamma_r}{S_{r,i}^2}\right] = 0$$

Similarly, imposing symmetry, the equilibrium quantity and speed for the two shipping sectors can be solved as

(9.1) $$\bar{q}_r = \frac{2a_r U_r\rho - 3D_r\sqrt[3]{2\rho(\eta+\chi)\lambda_r{\gamma_r}^2}}{2U_r\rho b_r[(N_r+1)+\nu_r]}$$

(9.2) $$\bar{S}_r = \sqrt[3]{\frac{\gamma_r}{2\rho(\eta+\chi)\lambda_r}} > 0$$

and fuel consumption is

(9.3) $$\bar{F}_r = \frac{\sqrt[3]{2\rho\lambda_r{\gamma_r}^2}D_r(2a_r U_r\rho - 3D_r\sqrt[3]{2\rho(\eta+\chi)\lambda_r{\gamma_r}^2})}{4\sqrt[3]{(\eta+\chi)^2}U_r^2\rho^2 b_r[(N_r+1)+\nu_r]}$$

The non-negativity of $\bar{q}_r$ and $\bar{F}_r$ implies that $2a_r U_r\rho > 3D_r\sqrt[3]{2\rho(\eta+\chi)\lambda_r{\gamma_r}^2}$. Compared to the solutions in (5), it is observed that, under the open ETS, the equilibrium solutions in (9) are equivalent to adding the emission permit price $\chi$ to the fuel price $\eta$. From (6), we know that $\partial\tilde{q}_r/\,\partial\eta < 0$, $\partial\tilde{S}_r/\,\partial\eta < 0$ and $\partial\tilde{F}_r/\,\partial\eta < 0$. Therefore, it is clear that under the open ETS, for any $\theta$<1 and $\chi > 0$, the fuel consumption, traffic quantity and ship speed of the carriers will decrease.

Note that the target emission reduction percentage $(1-\theta)$ does not affect the equilibrium fuel consumption volume, traffic quantity or speed (as $\theta$ does not enter the FOCs for optimization problem (7)). However, $\theta$ determines the trading behavior of the shipping industry with other sectors under the open ETS. Define $\theta_r'$ as the ratio of fuel usage in the open ETS to that in the case of no ETS, i.e.,

(10) $$\theta_r' = \frac{\bar{F}_r}{\tilde{F}_r} = \sqrt[3]{(\frac{\eta}{\eta+\chi})^2}\,\frac{(2a_r U_r\rho - 3D_r\sqrt[3]{2\rho(\eta+\chi)\lambda_r{\gamma_r}^2})}{(2a_r U_r\rho - 3D_r\sqrt[3]{2\rho\eta\lambda_r{\gamma_r}^2})} < 1$$

When $\theta > \theta_r'$, a carrier sells its emission permits to other sectors. When $\theta < \theta_r'$, a carrier buys permits. $\theta_r'$ is a decreasing function of $\chi$. That is, when the price of emission permits increases, carriers have a stronger incentive to reduce fuel usage and sell emission permits. Also, it is interesting to note that $\theta_r'$ is not dependent on market competition indicator $\nu_r$. This indicates that the market structure has no effects on the degree of emission abatement of the international shipping industry under the open ETS. This is a new finding not yet identified in previous studies.

Due to the fact that most of the containerships are newer than dry bulk ships, it is generally believed that container ships are more expensive (larger $\gamma$) and fuel efficient (smaller $\lambda$) than dry bulk ships. If such a condition holds, it is possible to analyze the differential impacts of an open ETS on the two shipping sectors. Define the proportional reduction in output and speed as in (11.1) and (11.2) respectively:

(11.1) $$R_r = \frac{\tilde{q}_r - \bar{q}_r}{\tilde{q}_r}$$

(11.2) $$T_r = \frac{\tilde{S}_r - \bar{S}_r}{\tilde{S}_r}$$

Taking partial derivatives of $R_r$ and $\theta'_r$ w.r.t. $\gamma_r$ and $\lambda_r$, it can be shown that $\partial R_r / \partial \gamma_r > 0$, $\partial R_r / \partial \lambda_r > 0$,$\partial \theta'_r / \partial \gamma_r < 0$, and $\partial \theta'_r / \partial \lambda_r < 0$. These comparative statics indicate that a higher ship operational cost (larger $\gamma_r$) and lower fuel efficiency (larger $\lambda_r$) can make carriers reduce proportionally more output and use less fuel. Thus, there are strong economic incentives for carriers to upgrade their fleets with more cost-effective ships, reduce ship operational costs and improve fuel efficiency. The differential impacts of an open ETS on the dry bulk and container sectors will be examined using numerical simulation, since it involves all the industry-specific parameter values for $a_r$,$U_r$,$D_r$ ,$\lambda_r$ ,$\gamma_r$.

Interestingly, substituting (5.1) and (9.2) into (11.2) leads to $T_r = 1 - \sqrt[3]{n/(\eta + \chi)}$, which shows that $T_r$ depends only on fuel price $\eta$ and permit price $\chi$. This implies that container ships and dry bulk ships will have the same proportional speed reduction.

To examine the impacts of the permit price on the profit of shipping lines, substitute the values of $\bar{q}_r, \bar{S}_r, \bar{F}_r$ back into the profit function, and totally differentiate that with respect to (w.r.t.) $\chi$, we get:

(12) $$\frac{d\bar{\pi}_{r,i}}{d\chi} = \underbrace{\frac{\partial \bar{\pi}_{r,i}}{\partial q_{r,i}} \frac{\partial q_{r,i}}{\partial \chi} + \sum_{j \neq i}^{N_r} \frac{\partial \bar{\pi}_{r,i}}{\partial q_{r,j}} \frac{\partial q_{r,j}}{\partial \chi}}_{\geq 0} + \underbrace{\frac{\partial \bar{\pi}_{r,i}}{\partial S_{r,i}} \frac{\partial S_{r,i}}{\partial \chi}}_{=0} + \underbrace{\frac{\partial \bar{\pi}_{r,i}}{\partial \chi}}_{\geq\, or < 0}$$

$$= (\nu_r - N_r + 1) b_r \bar{q}_r \frac{\partial \bar{q}_r}{\partial \chi} - [\rho \lambda_r \bar{S}_r^{\,3} \frac{\bar{q}_r D_r}{U_r \bar{S}_r \rho} - \theta \tilde{F}_r]$$

Since $\nu_r \leq N_r - 1$and $\bar{q}_r / \partial \chi < 0$, the first expression$(\nu_r - N_r + 1) b_r \bar{q}_r \frac{\partial \bar{q}_r}{\partial \chi}$ is non-negative. This can be regarded as a "freight market" effect. An increase in $\chi$ reduces each carrier's output level $\bar{q}_r(\chi)$, leading to a higher freight rate. This is similar to collusion among carriers aiming at reducing their outputs jointly and increasing their profits. The second term, $-[\rho \lambda_r \bar{S}_r^{\,3} \bar{q}_r D_r / (U_r \bar{S}_r\, \rho) - \theta \tilde{F}_r]$, can be regarded as an "emission market" effect, which is negative when a shipping company buys permits and positive when a shipping company sells emission permits. The overall effect on a carrier's profit depends on the relative strength of these two effects. If the demand for shipping service is elastic, or the price of the emission permit is high, the sign for $d\bar{\pi}_{r,i}/d\chi$ will be positive.

From (12), it is also clear that the impact on a carrier's profit w.r.t. permit price depends on the initial emission permit quota, the carriers' competition behavior, and the degree of competition as measured by the number of competing shipping firms (i.e., parameters $\theta$, $\nu_r$ and $N_r$ respectively). It can be further concluded that, in the case of perfect collusion among carriers (i.e., $\nu_r = N_r - 1$), shipping firms' profits will decrease with $\chi$ and be lower than the benchmark case (without ETS) for any given $\theta$. In the case of Bertrand competition among carriers (i.e., $\nu_r = -1$), shipping firms' profits will always be higher than the benchmark case. In the case of Cournot competition (i.e., $\nu_r = 0$), the change in a carrier's profit will depend on the proportion of emission allowance allocated. If the initial allocation is small, so that $\theta < 2/(N_r + 1)$, shipping firms' profits will decrease with $\chi$ as in the perfect collusion case. However, if the initial allocation is large, so that $\theta \geq 2/(N_r + 1)$, shipping firms' profits will increase. [3]

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[3]The profit function is convex in $\chi$ as $\frac{d^2\bar{\pi}_{r,i}}{d\chi^2} \geq 0$. $\left.\frac{d\bar{\pi}_{r,i}}{d\chi}\right|_{\chi=0}$ is a monotonic increasing function in $\theta$. $\left.\frac{d\bar{\pi}_{r,i}}{d\chi}\right|_{\chi=0} > (\leq) 0$ when $\theta > (\leq) \frac{2(\nu_r+1)}{(N_r+1)+\nu_r}$. For a perfect collusion case ($\nu_r = N_r - 1$), we have $\left.\frac{d\bar{\pi}_{r,i}}{d\chi}\right|_{\chi=0} \leq 0$ regardless of the value of $\theta$. Then the profit will decrease when $\chi$ increases from zero. For

# 4. A maritime only ETS (METS)

In the case of a METS, the price of emission permits is not exogenous. Instead, it is the result of emission permit trade between the container and bulk sectors. In order to investigate the effects of permit trading, we first derive the equilibrium condition with the target emission level at $\theta\tilde{F}_r$($\theta$<*1*) and trade not being allowed. The problem for each sector is to maximize their respective profit with an equality constraint:

$$(13)\ Max_{q_{r,i},S_{r,i}}\pi_{r,i} = P_r q_{r,i} - (f_{r,i} + \gamma_r)\frac{q_{r,i}D_r}{U_r S_{r,i}\,\rho}$$

$$s.t. \quad \rho\lambda_r S_{r,i}^3 \frac{q_{r,i}D_r}{U_r S_{r,i}\,\rho} = \theta\tilde{F}_r$$

The Lagrangian function for this problem can be written as:

$$(14) \qquad L_{\phi_{r,i}} = P_r q_{r,i} - (f_{r,i} + \gamma_r)\frac{q_{r,i}D_r}{U_r S_{r,i}\,\rho} - \phi_{r,i}\left[\,\rho\lambda_r S_{r,i}^3 \frac{q_{r,i}D_r}{U_r S_{r,i}\,\rho} - \theta\tilde{F}_r\right]$$

where $\phi_{r,i} > 0$is the Lagrangian multiplier. The corresponding FOCs for the Lagrangian function (14) with respect to $q_{r,i}$,$S_{r,i}$ and $\phi_{r,i}$ can be derived as:

$$(15.1) \qquad \frac{\partial L_{\phi_{r,i}}}{\partial q_{r,i}} = a_r - 2b_r q_{r,i} - b_r \sum_{j\neq i}^{N_r} q_{r,j} - b_r q_{r,i}\sum_{j\neq i}^{N_r}\frac{\partial q_{r,j}}{\partial q_{r,i}} - \frac{D_r}{U_r S_{r,i}\,\rho}\left[\rho(\eta + \phi_{r,i})\lambda_r S_{r,i}^3 + \gamma_r\right] = 0$$

$$(15.2) \qquad \frac{\partial L_{\phi_{r,i}}}{\partial S_{r,i}} = -\frac{q_{r,i}D_r}{U_r\,\rho}\left[2\rho\,(\eta + \phi_{r,i})\lambda_r S_{r,i} - \frac{\gamma_r}{S_{r,i}^2}\right] = 0$$

$$(15.3) \qquad \frac{\partial L_{\phi_{r,i}}}{\partial \phi_{r,i}} = \rho\lambda_r S_{r,i}^3 \frac{q_{r,i}D_r}{U_r S_{r,i}\rho} - \theta\tilde{F}_r = 0$$

Imposing symmetry on equations (15) we have the following important equation:

$$(16) \qquad \theta\tilde{F}_r = \frac{\sqrt[3]{2\rho\lambda_r{\gamma_r}^2}\,D_r\left(2a_r U_r\rho - 3D_r\sqrt[3]{2\rho(\eta+\hat{\phi}_r)\lambda_r{\gamma_r}^2}\right)}{4\sqrt[3]{(\eta+\hat{\phi}_r)^2 U_r^2\rho^2}\,b_r[(N_r+1)+\nu_r]}$$

Parameter $\hat{\phi}_r$ is the shadow price of emission permits, or the contribution to the profit of a shipping firm by relaxing the emission constraint by one unit, *i.e.*$\frac{d\hat{\pi}_r}{d(\theta\tilde{F}_r)} = \hat{\phi}_r$. Clearly, when $\hat{\phi}_1 \neq \hat{\phi}_2$, both sectors have an incentive to trade if it is allowed. The sector with higher $\hat{\phi}_r$ will buy emission permits as long as the price is lower than its own shadow price. Any price $h$ between $\hat{\phi}_1$ and $\hat{\phi}_2$ will lead to a Pareto improvement for the two sectors compared to a case with no trading. In an efficient market, the trade of emission permits will continue until no sector has an incentive to trade, or until equilibrium is reached when the shadow prices of the two sectors are equal. Without loss of generality, assume $\hat{\phi}_1 > \hat{\phi}_2$ and thefollowing conditions hold, where $\overline{\Delta}$ denotes the number of emission permits traded by each container carrier

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the Bertrand case ( $\nu_r = -1$), we have $\left.\frac{d\bar{\pi}_{r,i}}{d\chi}\right|_{\chi=0} \geq 0$ regardless of the value of $\theta$. Thus the profit will increase strictly for positive $\chi$.

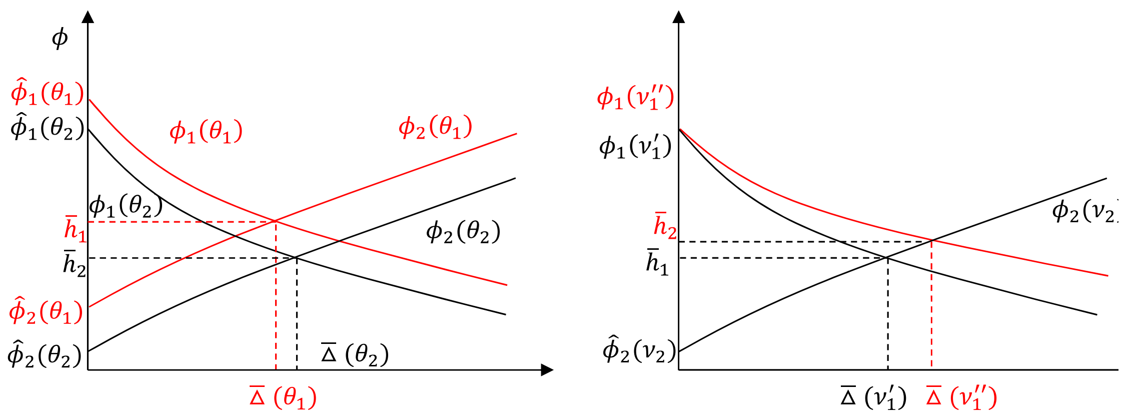
$$\begin{cases} \theta\tilde{F}_1 + \bar{\Delta} = \dfrac{\sqrt[3]{2\rho\lambda_1{\gamma_1}^2}D_1\left(2a_1U_1\rho - 3D_1\sqrt[3]{2\rho(\eta+\bar{h})\lambda_1{\gamma_1}^2}\right)}{4\sqrt[3]{(\eta+h)^2}U_1^2\rho^2b_1[(N_1+1)+\nu_1]} & (17.1) \\ \theta\tilde{F}_2 - \dfrac{N_1\bar{\Delta}}{N_2} = \dfrac{\sqrt[3]{2\rho\lambda_2{\gamma_2}^2}D_2\left(2a_2U_2\rho - 3D_2\sqrt[3]{2\rho(\eta+\bar{h})\lambda_2{\gamma_2}^2}\right)}{4\sqrt[3]{(\eta+h)^2}U_2^2\rho^2b_2[(N_2+1)+\nu_2]} & (17.2) \end{cases}$$

If the equilibrium price in the emission trading market is $\bar{h}$, the traffic quantity, ship cruising speed and fuel consumption for the two sectors are, respectively:

$$\hat{q}_r = \frac{2a_rU_r\rho - 3D_r\sqrt[3]{2\rho(\eta+\bar{h})\lambda_r{\gamma_r}^2}}{2U_r\rho b_r[(N_r+1)+\nu_r]}, \hat{S}_r = \sqrt[3]{\frac{\gamma_r}{2\rho(\eta+\bar{h})\lambda_r}}, \hat{F}_r = \frac{\sqrt[3]{2\rho\lambda_r{\gamma_r}^2}D_r\left(2a_rU_r\rho - 3D_r\sqrt[3]{2\rho(\eta+\bar{h})\lambda_r{\gamma_r}^2}\right)}{4\sqrt[3]{(\eta+\bar{h})^2}U_r^2\rho^2b_r[(N_r+1)+\nu_r])} \quad (18)$$

Equations (18) are similar to the equilibrium results in the open ETS case (equation 9), except that the exogenous permit price in (9) is replaced by the equilibrium permit trading price $\bar{h}$. This implies that the impact of the METS will have the same effects on the performance of the two sectors as the open ETS, provided that the emission trading prices in the two systems are the same.

Intuitively, since the emission permit is a valuable resource (binding constraint), if the initial allocation of emission allowance is small, the shadow prices will be high, which will result in a high trading price. As shown in Figure 1(a), when the initial allocation increases from $\theta_1$ to $\theta_2$, the shadow prices of the two sectors decrease from the red curves to the black ones, because more permits are available. It is clear that a small initial allocation can push up the permit price.




(a) Change of $\bar{h}$ with $\theta$ ($\theta_1 < \theta_2$) (b) Change of $\bar{h}$ with $\nu_1$ ($\nu_1'' < \nu_1'$)

***Figure 1: Illustration of emission price change with θ and $\nu_1$***

To see how market structure affects the emission trading price, with (5.3), equation (17.1) can be rearranged as $\frac{\sqrt[3]{2\rho\lambda_1{\gamma_1}^2}D_1}{4U_1^2\rho^2b_1[(N_1+1)+\nu_1]}\left[\frac{\left(2a_1U_1\rho - 3D_1\sqrt[3]{2\rho(\eta+\phi_1)\lambda_1{\gamma_1}^2}\right)}{\sqrt[3]{(\eta+\phi_1)^2}} - \theta\frac{2a_1U_1\rho - 3D_1\sqrt[3]{2\rho\eta\lambda_1{\gamma_1}^2}}{\sqrt[3]{\eta^2}}\right] = \Delta_1$. Thus, for any $\Delta_1 > 0$, $\phi_1$ increases when $\nu_1$ decreases (see Figure 1(b)), and thus the resultant $\bar{h}$ is higher. Similarly, by rearranging (17.2), it can be proved that $\phi_2$ and resultant $\bar{h}$ rise in $\nu_2$.

The effect of carrier competition can be interpreted as follows. For the sector buying emission permits, when carriers compete more intensively (as measured by a smaller $\nu_i$), the emission permit will be traded at a higher price, as carriers are more aggressive in output expansion and thus require more emission permits. For the sector selling emission permits, increased market collusion and reduced output make any further output reduction costly (i.e. a higher shadow price). This of course pushes up the trading price in the market.

Finally, comparing the results of the open ETS and METS, it is clear that their impacts on the shipping industry are the same only if the emission trading prices in these two schemes are equal to each other. Of course, the emission price $\chi$ is exogenous in an open ETS, whereas $h$ is determined by the trades between shipping sectors as well as by the emission reduction target 1-$\theta$.

# 5. Model calibration and simulation results

In addition to the aforementioned analytical solutions, in this section we will calibrate the economic model so that the economic impacts of ETS on the shipping industry can be simulated and quantified. Real market data for the international shipping industry in year 2007 are adopted in the simulation. Average ship cruising speed and size are calculated using data from Buhaug et al. (2009, p.131). Container ships have an average speed of $\tilde{S}_1 = 23$ kts (nautical miles per hour), while a dry bulk ship's speed is $\tilde{S}_2 = 14$ kts. The average ship size is $U_1 = 23{,}000$ tons for a container ship, and $U_2 = 49{,}000$ tons for a dry bulk ship. In addition, it is assumed that a ship sails 24 hours a day, and spends 270 days at sea per year or $\rho = 270 \times 24 = 6{,}480$ hours (Buhaug et al., 2009).

International seaborne traffic data is available from the Review of Maritime Transport 2008 published by UNCTAD. In year 2007, the container sector carried $1{,}240$ million tons of cargo, and the dry bulk sector carried $4{,}100$ million tons. Based on the same data source, it can be calculated that the average freight rate for the container sector is $\tilde{P}_1 = \$180$/ton for an average voyage distance of $D_1 = 9{,}036$ nms (nautical miles). It is not possible to precisely identify the average voyage distance for dry bulk shipping, so for benchmark purposes it is assumed to be the same as for container shipping. The ship bunker fuel price is around $\eta$=\$350/ton (\$ stands for US dollar) in year 2007 (Yao et al., 2012). The most widely used containership type is the Post Panamax, with a capacity of around 6,000 TEUs.[4] Notteboom and Carriou (2009) estimated that a 6000-7000 TEUs containership burns 203.4 tons of bunker fuel per day at its design speed of 25 kts, which is equivalent to 8.475 tons per hour. As a ship's hourly fuel consumption is equal to $\lambda_r S_{r,i}^3$, the containership fuel efficiency is calculated as $\lambda_1 = 0.000542$. In terms of dry bulk ships, Chang and Chang (2013) estimated $\lambda_2$ as 0.0012168 for a Panamax ship, which is the most widely used type of dry bulk ship.

Dry bulk ships are mostly time-chartered on a trip or period basis, and freight rates fluctuate according to routes and time periods. In our study, $\tilde{P}_2$ is set to be \$48/ton, which is calculated based on the trip charter rate on the Brazil to China route for iron ore transport (UNCTAD, 2008).

Next we determine the number of firms in each sector. In the container sector, worldwide capacity shares of the top 15 operators in 2007 correspond to a Herfindahl-Hirschman Index (HHI) of 995, equivalent to $N_1 = 10$ symmetric firms competing in the market[5]. For the dry bulk market, it is assumed that there are $N_2 = 20$ symmetric dry bulk carriers in the market. This corresponds to an HHI concentration ratio of 500, reflecting the industry reality that the bulk sector is more competitive than the container sector[6]. It should be noted that we are using

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[4] Average ship size has been increasing over the years due to the existence of economies of scale, although geographical implications also play an important role in carriers' fleet choice (Cullinane & Khanna, 1999; 2000). Our model calibration reflects the status as of 2007.

[5] The 16th world's largest container liner, Hamburg Sud, only had 1.55% of the world's container capacity in year 2007. Such a small market share contributes little to the HHI index. Thus, only the top 15 container liners are considered in our study, so as to reduce the complexity in data compilation.

[6] Clarksons Shipping Intelligence Network database collected the fleet capacity (in DWT) for the world's top 50 dry bulk ship owners in 2007. The 50th ranked ship owner, Alpha Tanker & Frt, has a very small

world aggregate carrier numbers, whereas in reality the firm number on a particular route must be smaller. With respect to market conduct parameter $\nu_r$, it is assumed that $\nu_1 = 0.8$ and $\nu_2 = 0$. This assumption reflects the fact that the container shipping market is fairly collusive due to high market concentration and influential alliances among major shipping lines, while the dry bulk market is more competitive.

With the above assumptions, other parameters can be derived. By equation (5.1), a ship's annual operation cost $\gamma_r$ can be obtained thus, that $\gamma_1 = \$2.99 \times 10^7$ and $\gamma_2 = \$1.51 \times 10^7$. Finally, with the estimated $\gamma_r$ and the following two equations (19) and (20), the unknown parameters in the demand function, the fuel consumption and carrier profit without ETS are derived and summarized in Table 1.

(19) $$\tilde{P}_r = a_r - b_r\tilde{Q}_r$$

(20) $$\frac{\tilde{Q}_r}{N_r} = \tilde{q}_r = \frac{2a_rU_r\rho - 3D_r\sqrt[3]{2\rho\eta\lambda_r{\gamma_r}^2}}{2U_r\rho b_r[(N_r+1)+\nu_r]}$$

***Table 1: Derived parameter values in the benchmark case***

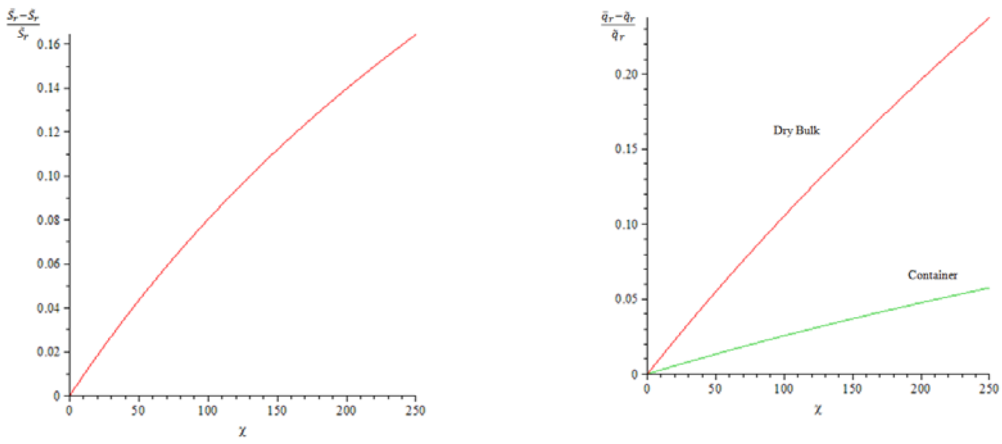
| **Parameter** | $a_1$(\$/ton) | $a_2$(\$/ton) | $b_1$(\$/ton$^2$) | $b_2$(\$/ton$^2$) |
|---|---|---|---|---|
| **Value** | 522.92 | 84.42 | $2.77 \times 10^{-7}$ | $8.88 \times 10^{-9}$ |
| **Parameter** | $\tilde{F}_1$ | $\tilde{F}_2$ | $\tilde{\pi}_1$ | $\tilde{\pi}_2$ |
| **Value** | $1.40 \times 10^7$ | $9.02 \times 10^6$ | $7.65 \times 10^9$ | $3.66 \times 10^8$ |

## *5.1 Model calibration for open ETS*

The analytical model suggests that under an open ETS, both the container and dry bulk sectors will have reduced speeds and outputs. This can be seen from the simulation result reported in Figure 2. The container and dry bulk sectors have the same proportional reduction in speed (Figure 2(a)). This is consistent with (11.2) because this proportion is dependent only on fuel price and emission permit price. However, as a container ship is faster, it will experience a larger absolute speed reduction. In terms of output, the dry bulk sector has a larger reduction proportionally (Figure 2(b)). This result is intuitive, because a dry bulk ship is much less fuel efficient, making it more sensitive to an effective increase in fuel price due to emission charges.

An increase in permit price will have a different impact on fuel usage in an open ETS, as shown in Figure 3. Figure 3(a) depicts the ratio of fuel usage $\theta_r'$ as derived in equation (10). It is clear that the container sector always uses more fuel than the dry bulk sector, indicating that it is more likely to buy permits than the dry bulk sector under an open ETS. It is also noted that the profits of dry bulk carriers are more significantly affected compared to container carriers under an open ETS (Figure 3(b)).

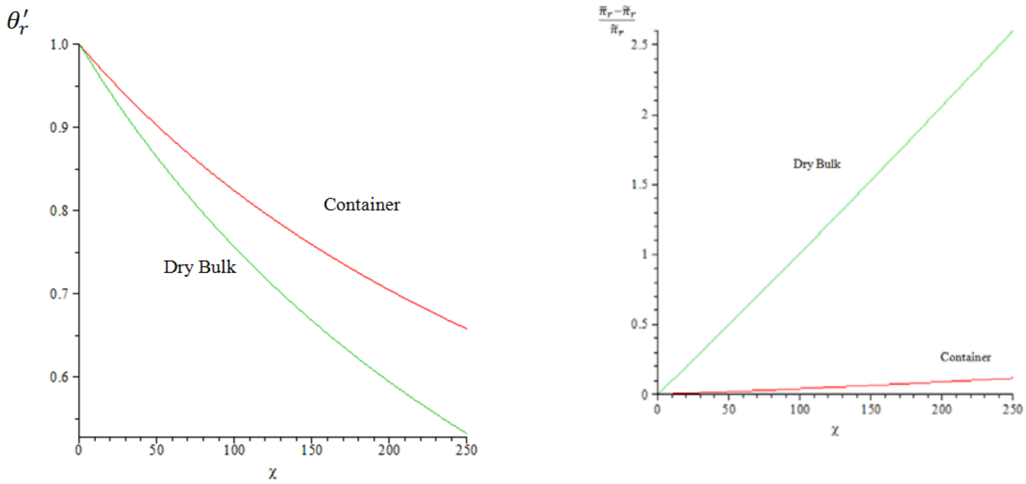
fleet of 29 ships. If only the top 50 dry bulk carriers reported by Clarksons are considered, the corresponding HHI is around 400, which is equivalent to 25 symmetric competitors. However, among these top 50 dry bulk carriers, some are not actively involved in international seaborne trade, thus the effective number of international dry bulk carriers should be even smaller. The assumption of $N_2 = 20$ should be a reasonable proxy.




(a) speed

(b) output

***Figure 2: Proportional reduction in ship speed and output with $\chi$***




Ratio of fuel usage w.r.t. $\chi$ under an open ETS

Proportional profit change w.r.t. $\chi$ under an open ETS ($\theta = 0.5$)

***Figure 3: The impacts of permit price on the fuel usage ratio and profit change***

## *5.2 Model calibration for METS*

For the METS, with the calibrated parameters, shadow prices $\hat{\phi}_r$ and resultant market clearance permit prices $\bar{h}$ can be simulated using equations (16) and (17). The simulation results are collated in Table 2. The initial allocation factor is set from 0.6 to 0.95, as too small a factor will result in too much reduction in international shipping output.[7] The simulation results indicate that the container sector always has a higher shadow price ($i.e., \hat{\phi}_1 > \hat{\phi}_2$), and will thus purchase emission permits from the dry bulk sector. This is intuitive, since fuel is more valuable to the container sector, which has a much higher freight rate and employs more fuel efficient vessels.

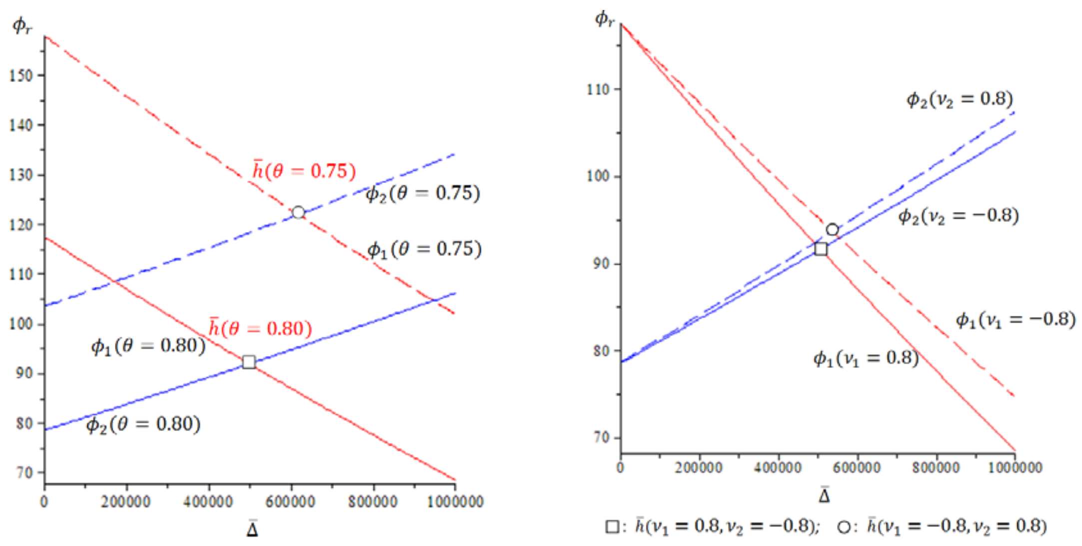
[7] Our calibration results suggest that when $\theta = 0.5$, the shipping volume will reduce by 30% for the dry bulk sector and 8% for the container sector. Such dramatic output reductions would impose a serious impact on international trade and economy, and is certainly unacceptable to the shipping industry.

***Table 2: Equilibrium of an METS for different values of $\theta$ given $\nu_1 = 0.8$ and $\nu_2 = 0$***

| $\theta$ | $\bar{h}$($/ton) | $\bar{\Delta}$(ton) | $\hat{\phi}_1$($/ton) | $\hat{\phi}_2$($/ton) |
|---|---|---|---|---|
| 0.95 | 19.6 | $1.27 \times 10^5$ | 24.3 | 17.1 |
| 0.90 | 41.3 | $2.53 \times 10^5$ | 51.5 | 35.7 |
| 0.85 | 65.3 | $3.76 \times 10^5$ | 82.4 | 56.1 |
| 0.80 | 92.0 | $4.99 \times 10^5$ | 117.6 | 78.6 |
| 0.75 | 121.9 | $6.18 \times 10^5$ | 157.9 | 103.4 |
| 0.70 | 155.6 | $7.35 \times 10^5$ | 204.7 | 130.9 |
| 0.65 | 193.9 | $8.50 \times 10^5$ | 259.3 | 161.6 |
| 0.60 | 237.7 | $9.61 \times 10^5$ | 323.9 | 196.0 |

The impacts of initial quota allocation and market structure on equilibrium outcomes can be directly observed from numerical simulations too, and these are in line with the analytical results reported in Figure 1. As illustrated in Figure 4(a), the price of emission permit $\bar{h}$ increases is higher when the initial allocation factor is smaller. Figure 4(b) illustrates the effects of market competition. Clearance price $\bar{h}$ increases when the emission permit buyer market (container sector in the simulation) becomes more competitive (with a lower $\nu_1$); and when the emission seller market (dry bulk sector) becomes more collusive (with a higher $\nu_2$). In recent years, efforts have been made by some governments and international agencies to maintain the level of competition in the container shipping sector (Lau et al., 2013). Whereas such a trend usually leads to larger market outputs, our simulation results suggest that an METS may impose a counter effect, since $\bar{h}$ will increase as the container shipping market becomes more competitive. This again demonstrates the complexity involved in designing realistic industry policies.

In addition, it is noted that the values of $\hat{\phi}_r$, $\bar{\Delta}$ and $\bar{h}$ are very sensitive to the change in $\theta$. A small reduction in permit allocation will result in a significant change to the market equilibrium of permit trading between the container and dry bulk sectors. Thus if an METS is chosen by the regulator, the value of $\theta$ should be carefully designed so as not to impose too dramatic an impact on shipping and international trade.




$\theta = 0.8$ and $\theta = 0.75$ different $\nu_i$ when $\theta = 0.8$

***Figure 4: Simulated change in permit price in an METS***

# 6. Summary and conclusions

Emission trading schemes have been proposed in order to reduce $CO_2$ emissions from the international shipping industry. However, despite the successful implementation of ETSs, such as the US $SO_2$ program and the EU ETS in previous years, there has been rather limited progress in reducing $CO_2$ emissions from the international shipping industry. Whereas numerous political and institutional factors might be blamed for such slow progress, certain important issues remain to be studied and evaluated concerning the ETS itself. An ETS involving the shipping industry can be either “open” or “closed”, and these would have differential impacts on the shipping industry. In addition, the shipping industry is not composed of homogeneous carriers. The market structure and company conduct also vary across different shipping sectors. Therefore, the ETSs under consideration would have differential impacts on the various shipping sectors, and thus differential effects on international trade.

This study analyzes and benchmarks the economic implications of two alternative ETS mechanisms, namely, an open ETS compared with an METS. The analytical solutions suggest that an ETS, whether open or maritime only, will decrease ship speed, carrier outputs and fuel consumption for both the container and bulk sectors, even in the presence of a “wind-fall” profit to shipping firms. Under an open ETS, the emission reduction target is a non-binding constraint, since carriers can trade their permits with other industries. The dry bulk sector will be more significantly affected compared to the container sector in terms of a higher proportional output reduction and more emission permits sold (or fewer permits used). Under an METS, the emission reduction limit will definitely be reached, and the permit price becomes endogenously determined by the trading behavior and market structure of both the container and dry bulk sectors. Under an METS, the degree of competition in a sector will have spill-over effects on the other sector. Specifically, when the sector that sells (buys) permits is more collusive (competitive), the equilibrium permit price will rise.

For the purpose of obtaining practical conclusions and managerial insights, the analytical model is calibrated using market data for the year 2007. In addition to validating the analytical conclusions, our simulations suggest that under an METS, container carriers will buy emission permits from the dry bulk side. The endogenous permit price will increase when the container (dry bulk) sector becomes more competitive (collusive). Therefore, it is difficult to predict the net effects on traffic volume when policies promoting competition in the container shipping market are introduced at the same time as emission trading schemes.

These analytical and calibration results probably explain why it has been so difficult to include the maritime sector in an ETS, whether it be an open scheme or a maritime only scheme. Although there is the possibility of “wind-fall” profits, the industry will suffer loss in both total cargo volume and operational efficiency (in terms of lower ship cruising speed) if an ETS is introduced. In addition, it is difficult even for the maritime industry itself to reach a consensus, since each shipping sector will experience differential impacts, and there may be spill-over effects across different markets. In addition, an ETS scheme could have interactive effects on other industrial policies affecting market competition. Therefore, there is still much uncertainty associated with the net effects of ETS schemes, although similar policies have been introduced in other industries. Our study reveals the complexity involved in maritime market analysis, and calls for comprehensive empirical investigations into policy design for this critically important industry.

As economic analysis of market-based measures (MBM) to reduce shipping $CO_2$ emissions has been scanty, our research provides timely insights for both regulators and industry practitioners to evaluate the effects of introducing an ETS into the various shipping sectors. It offers a framework to identify the moderating effects of market structure and competition between firms on emission reduction schemes, and emphasizes the importance of understanding the differential impacts of ETSs brought to individual sectors within an industry. Of course, our study is also subject to several limitations, which may be addressed in future research. First, shipping networks can change if an ETS is implemented regionally. Shipping firms might re-configure routes to avoid emission charges. Second, shipping demand can be uncertain, due to external economic shocks. A stochastic demand specification may be more realistic, which could lead to different choices of emission reduction targets. These investigations are natural extensions of our study, although beyond the scope of the present paper.

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