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Notes and comments

Is slow steaming a sustainable means of reducing CO_2 emissions from container shipping?

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ABSTRACT

Slow steaming strategies have been implemented by most shipping lines and significantly reduce CO_2 emissions from international shipping. This article measures the rate at which CO_2 emissions have been reduced for various container trades and estimates the bunker break-even price at which this strategy is sustainable in the long run. It is found that shows such reductions can only be sustained given a bunker price of at least \$350–\$400 for the main container trades.

1. Introduction

Slow steaming has become increasingly common in liner shipping as the amount of available capacity rises and the price of fuel increases. One positive effect of slow steaming is that it lowers CO_2 emissions that are proportional to the amount of fuel burned. This effect is worth studying, especially for container vessels, which represented 4% of all maritime vessels but generated 20% of emissions from international shipping in 2007 (Psaraftis Kontovas, 2009). Reducing a vessel's speed by 10% decreases emissions by at least 10–15% but also creates substantial losses in revenues (Psaraftis and Kontovas, 2010). This paper uses secondary data to provide a more accurate view of the impact of slow steaming on liner shipping CO_2 emissions since 2008, not on the global level but for specific trades subject to different rates of slow steaming.

2. Methodology

For containerships with a capacity of more than 1000 TEU using two-stroke marine diesel engines, a speed reduction from design speed (V_{ds}) to slow steaming (V_{ss}) for a vessel k impacts the main engine fuel consumption at sea ($ME_{k,sea}$), with a limited effect on the auxiliary engine[1] (Faber et al., 2010). Accordingly, the effect of a speed reduction on CO_2 emissions for a service with n vessels can be approximated as:

$$\Delta CO_{2,Vds\rightarrow Vss} = 3.17 \times \sum_{k=1}^{n} (ME_{k,sea} \times D_{k,sea} + ME_{k,port} \times D_{k,port}) = 3.17 \times \Delta FC_{Vds\rightarrow Vss} \qquad (1)$$

with

$$ME_{k,sea} = SFOC_k x EL_k x \text{ kW h}_k \qquad (2)$$

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[1] We omit periods during which vessels are hotelling or transiting through canals. We also ignore the fact that the use of bow thrusters and the number of reefer containers affect fuel consumption.

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Table 1
Main engine consumption at sea in tons/day at design speed.

Vessel size (TEU)	LRF database[a]			This paper[b]		
	Number of vessels	Design speed V_{ds}	ME_k at V_{ds}	Number of vessels	Design speed V_{ds}	ME_k at V_{ds}
1000–2000	94	19.4	53	249	19.6	53
2000–3000	100	20.9	81	368	21.8	89
3000–5000	152	22.9	128	644	23.6	143
5000–8000	93	24.8	209	420	24.9	220
8000+	12	24.4	258	249	24.6	272

[a] Four hundred and fifty-one vessels for which consumption at sea is provided.
[b] Thousand nine hundred and thirty vessels for which the engine kW h is known.

where the emission factor in kilograms of CO_2 emitted per ton of fuel burned by the main engine is 3.17; $D_{k,sea}$ is the number of days at sea; and $D_{k,port}$ is the number of days in ports. The main engine's daily fuel consumption at sea ($ME_{k,sea}$) is the product of specific fuel oil consumption ($SFOC_k$), engine load (EL_k) and engine power (kW h_k). Vessels are built for sailing close to design speed, which is 70–90% of the maximum continuous rate (MCR), a level at which the SFOC is optimal and at around 180–195 g/kW h. This value varies by engine type and can change in different weather conditions. We assume that fuel consumption in port ($ME_{k,port}$) is 5% of the main engine consumption at design speed (US Environmental Protection Agency, 2000).

The impact of slow steaming on fuel consumption depends on the speed reduction As long as the speed is reduced in small amounts up to a 10–15%, the SFOC remains fairly constant, a rule of thumb is that engine power is related to ship speed by a third power. When speed is reduced by more than 10%, perhaps to 30%, as assumed here, the engine load decreases to around 40% of MCR and the SFOC increases by up to 10%; a figure that varies according to engine characteristics, vessel type and engine age.[2]

We assume that when a vessel is sailing at close to that is the pre-slow steaming era, the SFOC is 195 g/kW h and the engine load is 90% of MCR. When the speed is reduced by 30%, the SFOC increases to 205 g/kW h. For a typical 4000 TEU containership with a 43,000 kW h engine and a design speed of 24 kn, this implies that fuel consumption at sea is 182 tons per day at design speed. When sailing 30% slower, at 17–18 kn, the fuel consumption is 85 tons per day; a 55% reduction. This reduction in fuel consumption is applied to slow steaming vessels, although differences exist in terms of vessels and trades.[3]

With slow steaming, however, the rotation is stretched by ΔRot, the average number of miles travelled in a year per vessel falls, although the time required in port for a particular service remains similar, as more vessels are deployed. In fact, additional vessels are required to maintain a weekly frequency at each port of call (Notteboom and Vernimmen, 2008). This implies that the long-term sustainability of slow steaming depends on the additional operational costs for the n vessels added (OC) and on changes in inventory costs (IC_{teu}), as containers spend more time at sea. The bunker price break-even point (BP^*) for which the reduction is sustainable is:

$$BP^* \geqslant \frac{\Delta OC_{ds\to ss} + \Delta Rot_{ds\to ss} x IC_{teu}}{\Delta FC_{ds\to ss}} \tag{3}$$

As long as the current bunker price is significantly more than BP^*, slow steaming is viable and one can expect that the reductions achieved in CO_2 emissions will be maintained.

3. CO_2 reductions from slow steaming, 2008–2010

An estimation of the impact of slow steaming on CO_2 emissions on the trade level requires information on the initial vessel's fuel consumption at sea at design speed ($ME_{k,sea}$), to which a 55% reduction will apply when that vessel is slow steaming, and on service characteristics, including the number of services and vessels under slow steaming, the days at sea and in port and the number of vessels deployed.

To determine $ME_{k,sea}$, information from *Lloyd's Register-Fairplay* (LRF, January 2010) was used. Table 1, provides details on the daily fuel consumption for 451 container vessels grouped into five categories. We compared these figures with our estimates based on a load factor of 90% and an SFOC of 195 g/kW h, which is multiplied by the engine's kW h. The latter information is available for 1930 vessels in LRF.

To assess the impact of slow steaming by trade, information was gathered from the Alphaliner (2010) database in January 2010. These identify the service in which a vessel is deployed for 2051 containerships with carrying capacity of more than 1000 TEU.[4] Furthermore, for each of the 387 services, the route, frequency, rotation in number of days and ports of call are gi-

[2] According to 1-year data gathered from a private operator for a 4300 TEU containership with a modern engine, the SFOC would only increase from 195 to 198 g/kW h and the fuel consumption at sea would fall by around 60% when speed is reduced by 30%.
[3] Even for the 4300 TEU vessel considered here, it runs at 10–20% of MCR, equivalent to 12–14 kn, 10% of the rotation.
[4] For the (2051–1930) vessels for which the engine kW h is not known, we assume that their consumption is equal to the mean of the category to which they belong (Table 1).

Table 2
Impact of slow steaming on annual fuel consumption per vessel (2008, 2010).

Vessel size (TEU)	Characteristics (2051 vessels)[a]				Days at sea		Average fuel oil consumption per ship (in '000 tons per year)		
	Number of vessels	% Vessels slow steaming	Mean size (TEU)	Design speed V_{ds}	2007[b] and 2008	2010	2007[b]	This paper (2008)	This paper (2010)
1000–2000	278	19.4	1481	19.5	241	244	9700	8997	8759
2000–3000	398	22.6	2542	21.7	247	250	15,600	15,409	14,666
3000–5000	677	37.2	4087	23.6	250	255	25,200	24,698	22,789
5000–8000	432	65.7	5948	24.9	251	260	37,500	36,695	31,541
8000+	266	75.5	9175	24.6	259	270	46,400	46,727	38,777

[a] Based on Alphaliner (2010).
[b] From Buhaug et al. (2009).

Table 3
Impact of slow steaming on CO_2 emissions by trade (2008, 2010)[a].

	Number of services	% services slow steaming	Number of vessels	% vessels slow steaming	Mean size in TEU	CO_2 emissions in 000 tons	% 2010/2008
Multi-trade	63	57.1	539	64.2	5994	47,500	−16.5
Europe/Far East	28	78.6	115	74.8	7720	12,900	−16.4
Asia/North America	52	42.3	323	47.1	5142	29,400	−9.7
North Atlantic	22	22.7	98	30.6	3469	5778	−6.7
Australasia/Oceania	17	23.5	96	27.1	3490	6275	−4.1
Latin America/Caribbean	73	20.5	314	24.2	2823	16,200	−4.8
Middle East/South Asia	87	23.0	342	25.7	3802	22,900	−6.7
South/East Africa	16	31.3	97	29.9	3007	5460	−5.9
West Africa	29	20.7	127	37.8	2106	4510	−9.1
Total	387	35.4	2051	42.9	4485	**150,921**	**−11.2**

[a] Calculations based on Alphaliner 2010).

ven. We retrieved information on the status of a service with regard to slow steaming from comments in the database on service history. Table 2 provides descriptive statistics for vessel size; 42.9% of vessels were slow steaming in January 2010 with the proportion of ships slow steaming rising with vessel size.

The number of days spent at sea in 2008 is assumed similar to Buhaug et al. (2009,) and as a result of the slow steaming, the average time at sea rose in 2010 from an average of 259–270 days. This increase is (Table 3) and is obtained by adding 2 weeks, one in each direction, to services reported to be slow steaming in 2010. For vessels deployed in a service under slow steaming, 35.4% of services in 2010), a 55% reduction in fuel consumption at sea is assumed. In 2008, the bunker consumption for the 2051 container vessels was 53.6 million tons. Even though 137 more vessels were used, bunker consumption and CO_2 emissions decreased by an estimated 11.1% in 2010 as a consequence of slow steaming.

Turning to trade differences, Table 3 shows the characteristics of 387 services aggregated into eight trades, with an additional category for multi-trades, services covering more than two trade routes, such as around-the-world and pendulum services. The largest number vessels are deployed in multi-trades (35.1% of capacity), followed by the Asia/North America (18.1% of capacity) and the Middle East/South Asia (14.1% of capacity) trades. The under-representation of the Europe/Far East trade is because most multi-trade services cover this leg. In January 2008, 78.6% of Europe/Far East services were under slow steaming, compared with 57.1% of multi-trades.

The decrease in emissions is 11.1% due to reductions in fuel consumption represents a fall from 170 million tons of CO_2 in 2008 to 151 million in 2010, with the greatest reduction is for vessels on the multi-trade and Europe/Far East services. This contrasts with smaller trades such as Australia/Oceania related trades which are subject to less slow steaming.

4. The sustainability of slow steaming

To determine the sustainability of slow steaming (Eq. (3)), the cost of adding vessels to a service under slow steaming as well as the increase in inventory costs for shippers must be considered. Operational costs vary according to the number of vessels added and their characteristics. We assume the former is proportional to the number of services under slow steaming, with one vessel added for each service. For these vessels, the average daily operational costs (OC_k) were retrieved from HSH Nordbank (2008). This figure was \$7000 per day for 1000–2000 TEU vessels, \$8000 per day for 2000–3000 TEU vessels,

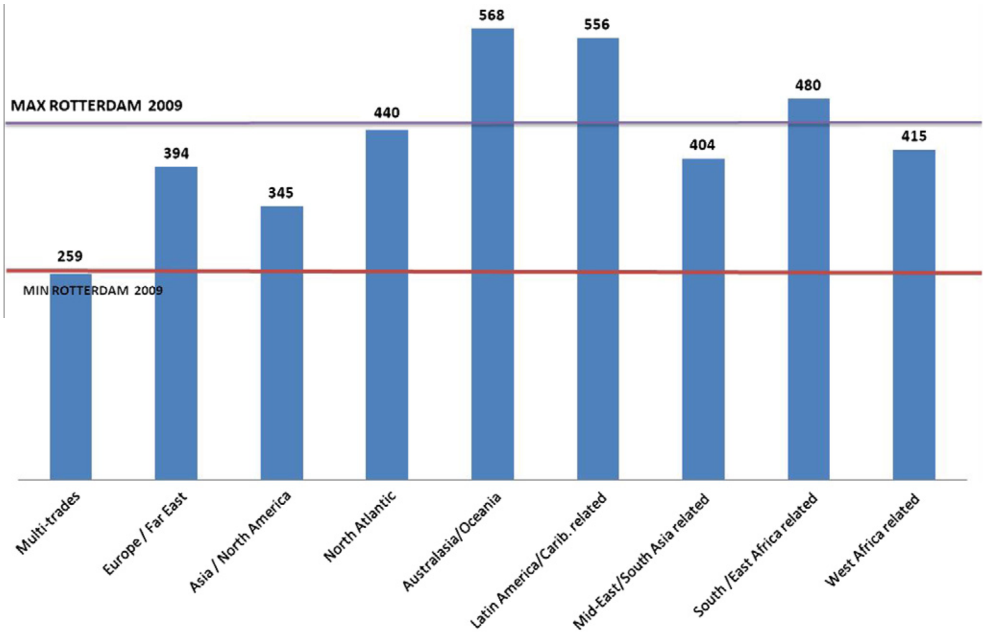

Fig. 1. Bunker price break-even point in $/ton.

and $9000 for 3000 TEU plus capacity vessels. To determine inventory costs, we rely on the estimate provided by Eefsen and Cerup-Simonsen (2010) of an average value of $27,331 per TEU, an annual interest rate of 35%, with 70% of full containers.

For instance, for multi-trades services in January 2010, we assume that 36 vessels (57.1% × 63) have been added to this trade since 2008. Given the characteristics of vessels on that trade, the average daily operating cost is $8833 and the break-even bunker price point is a function of:

- Annual savings on consumption, derived from Table 3, which are equal to (56,900,000–47,500,000)/(2 × 3.17) = $1482,000 tons of fuel.
- Additional operational costs, which are equal to $116 million for the 36 additional vessels.
- In-transit inventory costs equal to $266 million for 70% of the 64.2% × 3.2 million TEU that are spending one additional week at sea.

The bunker break-even price for multi-trade services at which slow steaming would be viable is then equal to $259 per ton of IFO. Given current bunker prices, suggesting that vessels are unlikely to return to normal speeds and companies are unlikely to remove the additional capacity in multi-trade services in the near future. Fig. 1 presents the results for all trades.

The findings have a number of implications. In the Australia/Oceania, Latin America/Caribbean trades, the percentage of services under slow steaming are relatively low and the bunker break-even point is relatively high as a result of the low ratio between time at sea, when savings occur, and time in port. For these services, BP^* is more than $550. For the sake of comparison, the IFO bunker price in Rotterdam fluctuated between $260 and $470 per ton in 2009. For many trades, the break-even point is close to the average value observed in Rotterdam. For these markets, the implementation of a tax levy (Marine Environment Protection Committee, 2009a) of around $50 could be enough to pass the break-even point.

5. Conclusions

This paper shows that slow steaming has reduced emissions by around 11% over the past 2 years; close to the target of a 15% reduction by 2018 that was proposed by the International Maritime Organisation's Marine Environment Protection Committee, 2009b). Furthermore, the reduction is achieved without the adoption of any new technology in the short run but remains fragile in the long run. Indeed, if bunker prices fall while freight rates and inventory costs rise, the profit motives for operating a vessel at full speed are likely to rise. Since this is likely to cause freight rates to rise, slow steaming can only remain sustainable if bunker prices remain high or if powerful market-based solutions, such as tax levies and/or cap-and-trade systems, are implemented to sustain bunker prices. However, a variety of technical elements were not considered. At very slow speeds, additional consumption occurs, the quality of the exhaust is altered and such slow speeds can give rise to design and safety issues.

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