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

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Abstract

Reductions in speed significantly reduce CO_2 emissions from international shipping. Slow steaming strategies, which were not sustainable a few years ago when the container markets were booming, have been implemented by most shipping lines. This article attempts to measure the rate at which CO_2 emissions have already been reduced and to estimate the bunker break-even price at which slow steaming is sustainable for various trades in the long run. The paper shows that such reductions, such as the estimated 11% decrease in emissions since 2008, can only be sustained given a bunker price of at least $350-400 for the main east-west trades.

Keywords:

CO_2 emissions; container shipping; slow steaming; bunker prices.

1. Introduction

Slow steaming, or the reduction in the sailing speed of maritime vessels, has become increasingly common as the amount of available capacity rises and the price of fuel increases. In the container segment, the delivery of 240 container vessels from March 2007 to March 2009 increased capacity by 10% (Alphaliner, 2010a). During the same period, demand fell by 10% (UNCTAD, 2009). As a result, more than 500 containerships were idle in January 2010. Furthermore, the price for IFO 380cst bunkers (intermediate fuel oil) reached $700 per ton in July 2008, compared to $300 in January 2007 and $400 today. In this respect, slow steaming strategies help shipping companies address over-capacity issues and surges in fuel costs.[1]

One positive effect of slow steaming is that it lowers CO_2 emissions. Emissions are proportional to the amount of fuel burned – around 3.17 kilograms of CO_2 are emitted per ton of fuel burned (Endresen et al., 2003; Buhaug et al., 2009; Corbett et al., 2003, 2007, 2009; Eyring et al. 2005a, 2005b, 2009). This effect is worth studying, especially for container vessels, which represented 4% of all maritime vessels but generated 20% of emissions from international shipping – around 206 million tons of CO_2 in 2007 (Buhaug et al., 2009; Psaraftis et al., 2009). Reducing a vessel's speed by 10% decreases CO_2 emissions by at least 10-15% (Corbett et al., 2009; Eide et al., 2009; Longva et al., 2010), but such reductions also create substantial losses in revenues, as the time at sea and the number of vessels required to maintain a weekly frequency increase (Kollamthodi et al., 2008; Corbett et al., 2009; Psaraftis et al., 2010).

This paper attempts to provide an accurate view of the impact of slow steaming by measuring its effect on liner shipping CO_2 emissions since 2008 and its sustainability in the long term. To do so, this paper begins with a presentation of the methodology used and a discussion of how slow steaming influences emissions. Estimates are then aggregated by trade route using data on 2,051 containerships deployed on 387 services in January 2010. The final section offers

1 According to Maersk Line's Chief Operating Officer, Morten Engelstoft, "Slow steaming is here to stay" (Engelstoft, 2010).

a calculation of the bunker price break-even point at which slow steaming is sustainable and ends with a discussion of the policy implications of the findings.

2. Methodology

For containerships with a capacity to carry more than 1,000 TEU using two-stroke marine diesel engines, a speed reduction from design speed (ds) to slow steaming (ss) for a vessel k impacts the main engine fuel consumption at sea ($ME_{k,sea}$), with a limited effect on the auxiliary engine. Accordingly, the effect of a speed reduction on CO_2 emissions for a service *w* operated with *n* vessels can be approximated as follows:

$$\Delta CO_{2,ds \rightarrow ss} = 3.17x\sum_{k=1}^{n}\left(ME_{k,sea}xD_{k,sea} + ME_{k,port}xD_{k,port}\right) = 3.17x\Delta FC_{ds \rightarrow ss} \quad (1)$$

With $ME_{k,sea} = SFOC_k xEL_k xkWh_k$ (2)

3.17 is the emission factor and represents the amount of kilograms of CO_2 emitted per ton of fuel burned by the main engine (Buhaug et al., 2009; Corbett et al., 2009). $D_{k,sea}$ is the number of days at sea equal to (distance/speed), while ($D_{k,sea}$ + $D_{k,port}$) is the number of days to complete a rotation, or Rot_w.

$ME_{k,sea}$ is the main engine's daily fuel consumption at sea and is the product of specific fuel oil consumption ($SFOC_k$), engine load (EL_k) and the engine power (kWh_k). We assume that fuel consumption in port ($ME_{k,port}$) is 5% of the main engine consumption at sea at design speed (EPA, 2000).[2] 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/kWh. This value varies by engine type and can change in different weather conditions.

The impact of slow steaming on fuel consumption depends on the magnitude of the speed reduction (MAN B&W Diesel A/S, 2008; Buhaug et al., 2009; Psaraftis et al., 2010; Faber et al., 2010). As long as the speed is reduced in small amounts

[2] 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.

up to a 10-15% reduction, the SFOC remains fairly constant. As a rule of thumb, engine power is related to ship speed by a third power. When speed is reduced by more than 10%, perhaps to 30% (as assumed in this article), the engine load decreases to around 40% of MCR and the SFOC increases by up to 10%. This latter figure varies on the basis of engine characteristics, vessel type and engine age. Engine retrofitting can limit the increase in SFOC.[3]

We assume that when a vessel is sailing at close to its optimal speed, or the pre-slow steaming era, the SFOC is 195 g/kWh and the engine load is 90% of MCR. When the speed is reduced by 30%, the SFOC increases to 205 g/kWh. For a typical 4,000 TEU containership with a 43,000 kWh engine and a design speed of 24 knots, this implies that fuel consumption at sea is 43,000 x 0.9 x 195 x 24/ 1,000,000 = 182 tons per day at design speed. Therefore, when sailing at a 30% slower speed of 17-18 knots, the fuel consumption per day is 43,000 x 0.40 x 205 x 24/1,000,000 = 85 tons per day. This equals a 55% reduction in fuel consumption at sea. In this paper, these average values are applied to all vessels, although differences exist in terms of vessels and trades. Furthermore, in reality, vessels do not always sail at a constant speed.[4]

However, the impact of slow steaming is not limited to its impact on the main engine's fuel consumption at sea. With slow steaming, the rotation is stretched by ($\Delta Rot = Distance_W/24(s_{ds}-s_{ss})$) days, the average number of miles travelled in a year falls and the number of ports of call decline, although the total time required in port for a particular service remains similar, as more vessels are deployed.[5] In fact, additional vessels ($\Delta n= n_{ds}-n_{ss}$) are required to maintain a weekly frequency at each port of call (Notteboom et al., 2008, 2009; Corbett et al., 2009; Psaraftis et

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[3] According to one-year data gathered from a private operator for a 4,300 TEU containership with a modern engine, the SFOC would only increase from 195 to 198 g/kWh and the fuel consumption at sea would fall by around 60%.

[4] For instance, for the 4,300 TEU vessel considered, the vessel runs at 10-20% of MCR, equivalent to a speed of 12-14 knots, 10% of the rotation.

[5] We assume that the time spent in ports for all vessels for any particular service remains the same. If ($D_{port,ss}<D_{port,ds}$) is not true, then: i) there is no specific need for additional Δn_{w1} vessels or for the stretching of the rotation ($Rot_{ss}=Rot_{ds}$), as long as the number of ports dropped compensate for the time lost at sea ($D_{sea,ss}>D_{sea,ds}$); and ii) the mean number of miles performed in a year still decreases but, in this case, this is the result of the reduction in distance. This option still reduces fuel costs but at the expense of a significant deterioration in the quality of service, as the number of ports of call is lower.

al, 2010). This implies that the long-term sustainability of slow steaming depends on the additional operational costs for the *n* vessels added ($OC_{\Delta n}$) and on changes in inventory costs (IC_{teu}), as containers spend more time at sea (ΔRot) when vessels are slow steaming. The bunker price break-even point (BP*) for which the observed reduction is sustainable is then:

$$BP^* \geq \frac{OC_{\Delta n, ds \rightarrow ss} + \Delta Rot_{ds \rightarrow ss} x IC_{teu}}{\Delta FC_{ds \rightarrow ss}} \quad (3)$$

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 two pieces of information: 1) the 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 2) service characteristics, including the number of days at sea (D_{sea}) and in port (D_{port}), as potential reductions only apply when the vessel is at sea. To determine $ME_{k,sea}$, information from *Lloyd's Register-Fairplay* (LRF, January 2010) was used. Table 1, Panel A, provides details on the daily fuel consumption for 451 container vessels grouped into five categories. We compared these figures with our estimates (Table 1, Panel B) based on a load factor of 90% and an SFOC of 195 g/kWh, which is multiplied by the engine's total kWh. The latter information is available for 1,930 vessels in LRF.

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

	A. LRF database[a]			**B. This paper[b]**		
Vessel size (TEU)	Number of vessels	Design speed S_{ds}	ME_k at S_{ds}	Number of vessels	Design speed S_{ds}	ME_k at S_{ds}
1,000-2,000	94	19.4	53	249	19.6	53
2,000-3,000	100	20.9	81	368	21.8	89
3,000-5,000	152	22.9	128	644	23.6	143
5,000-8,000	93	24.8	209	420	24.9	220
8000+	12	24.4	258	249	24.6	272

[a] 451 vessels for which consumption at sea is provided.
[b] 1,930 vessels for which the engine kWh is known.

To assess the impact of slow steaming by trade, information was gathered from the Alphaliner database in January 2010 (Alphaliner, 2010b). Alphaliner identifies the service in which a vessel is deployed for 2,051 containerships with carrying capacity of more than 1,000 TEU.[6] Furthermore, for each of the 387 services, the route, frequency, rotation in number of days and ports of call are given. We retrieved information on the status of a service with regard to slow steaming from comments in the database on service history. Table 2, Panel A, provides descriptive statistics for vessel size. The mean vessel size is 4,485 TEU and the mean design speed 23.8 knots. 42.9% of vessels were slow steaming in January 2010 (Table 2, Panel A), and the proportion of ships that were slow steaming rises as vessel size increases (for example, 75.5% of 8,000+ TEU containerships were slow steaming).

The number of days spent at sea in 2008 in our data is similar to the finding of Buhaug et al. (2009, p. 195). Fuel consumption in port is assumed to be 5% of values reported in Table 1. For vessels deployed in a service under slow steaming (35.4% of services and 42.9% of vessels in 2010), a 55% reduction in fuel consumption at sea is assumed. However, as a result of the slow steaming, the average time at sea rose from 2008, particularly for larger vessels, from an average of 259 days to 270 days (Table 3, Panel B). This result is obtained by adding two weeks (one each direction) to services reported to be slow steaming in 2010 (Rot_{ss}=Rot_{ds} + 14 days). In 2008, the total bunker consumption for the 2,051 container vessels (number of vessels per category x average consumption) was an estimated 53.6 million tons. Even though 137 more vessels were used in 2010 (see the next section), total bunker consumption (and CO_2 emissions) decreased by an estimated 11.1% to 47.6 million tons in 2010 as a consequence of slow steaming.

A similar analysis was done according to trade. Table 3 shows the characteristics of 387 services aggregated into eight trades, with an additional category for

[6] For the (2,051-1,930) vessels for which the engine kWh is not known, we assume that their consumption is equal to the mean of the category to which they belong (Table 1).

multi-trades (services covering more than two trade routes, such as around-the-world and pendulum services). The most vessels are deployed in multi-trades (26.3% of vessels; 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 explained by the fact that 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. Furthermore, the vessels deployed on the Europe/Far East and multi-trade services are generally larger, with mean sizes of 7,720 TEU and 5,994 TEU, respectively.

Finally, Table 4 compares CO_2 emissions, by trade and vessel size in 2008 and 2010, with the later being the slow-steaming era. The decrease in emissions is estimated to be 11.1% (based on reductions in fuel consumption), falling from 170 million tons of CO_2 in 2008 to 151 million in 2010. The greatest reduction is seen for vessels with a capacity of 8,000+ TEU (17% reduction), followed by vessels on the multi-trade (-16.5%) and Europe/Far East services (-16.4%). This result contrasts with smaller trades such as Australia/Oceania related trades (-4.1%) which are subject to slow steaming to a lesser extent.

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

	A. Characteristics (2,051 vessels)[a]				**B. Days at sea**		**C. Average fuel oil consumption per ship (in '000 tons per year)**		
Vessel size (TEU)	Number of vessels	% in ss	Mean size (TEU)	Design speed s_k	2007[b] and 2008	2010	2007[b]	This paper (2008)	This paper (2010)
1,000-2,000	278	19.4	1,481	19.5	241	244	9,700	8,997	8,759
2,000-3,000	398	22.6	2,542	21.7	247	250	15,600	15,409	14,666
3,000-5,000	677	37.2	4,087	23.6	250	255	25,200	24,698	22,789
5,000-8,000	432	65.7	5,948	24.9	251	260	37,500	36,695	31,541
8,000+	266	75.5	9,175	24.6	259	270	46,400	46,727	38,777

[a] Calculation based on Alphaliner database (2010).
[b] From Buhaug et al. (2009, pp. 195 and 214).

Table 3. Main characteristics of services, January 2010[a]

	Number of services	**% of services slow steaming**	**Number of vessels**	**% of vessels slow steaming**	**Total capacity (TEU)**	**Mean Number of vessels**	**Mean Rotation days**	**Mean Ports of call**	**Mean Size (TEU)**	**Mean Speed (kt)**
Multi-trade	63	57.1	539	64.2	3,230,508	8.6	72	16	5,994	24.0
Europe/Far East	28	78.6	115	74.8	887,769	4.1	66	14	7,720	24.8
Asia/North America	52	42.3	323	47.1	1,661,017	6.2	50	10	5,142	24.3
North Atlantic	22	22.7	98	30.6	339,966	4.5	40	10	3,469	22.2
Australasia/Oceania	17	23.5	96	27.1	335,002	5.6	44	10	3,490	23.1
Latin America/Caribbean	73	20.5	314	24.2	886,568	4.4	47	13	2,823	21.8
Middle East/South Asia	87	23.0	342	25.7	1,300,282	3.9	39	11	3,802	22.7
South/East Africa	16	31.3	97	29.9	291,649	5.7	50	9	3,007	21.7
West Africa	29	20.7	127	37.8	267,517	4.4	53	9	2,106	20.7
Total	387	35.4	2,051	42.9	9,200,278	5.3	53	12	4,485	23.1

[a] Calculations based on Alphaliner database (January 2010).

Table 4. Impact of slow steaming on CO_2 emissions by trade (2008, 2010)[a]

	Baseline – 2008 Pre-slow steaming ('000 tons CO_2)	January 2010 – Slow steaming era ('000 tons CO_2)	% reduction 2008-2010
Trade			
Multi-trades	56,900	47,500	-16.5
Europe/Far East	15,500	12,900	-16.4
Asia/North America	32,600	29,400	-9.7
North Atlantic	6,191	5,778	-6.7
Australasia/Oceania	6,544	6,275	-4.1
Latin America/Caribbean	17,000	16,200	-4.8
Middle East/South Asia	24,600	22,900	-6.7
South Africa/East Africa	5,800	5,460	-5.9
West Africa	4,963	4,510	-9.1
Vessel size (TEU)			
1,000-2,000	7 ,929	7 ,719	-2,6
2,000-3,000	24,000	18,500	-4,8
3,000-5,000	53,000	48,900	-7,7
5,000-8,000	50,300	43,200	-14,0
8,000+	39,400	32,700	-17,0
Total	**170,097**	**150,921**	**-11.2**

[a] Calculations based on Alphaliner database (January 2010) and LRF (2010).

4. The sustainability of slow steaming

To determine the sustainability of slow steaming (equation 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 on the basis of the number of vessels added and their characteristics. We assume that the number of vessels added 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 $7,000 per day for 1,000-2,000 TEU vessels, $8,000 per day for 2,000-3,000 TEU vessels, and $9,000 per day for vessels with a capacity of more than 3,000 TEU. 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 and an annual interest rate of 35%.

For instance, as 57.1% of the 63 multi-trades services were under slow steaming in January 2010, we assume that 36 vessels (57.1% x 63) have been added to this trade since 2008. Given the characteristics of vessels deployed on multi-trade services, the average daily operating cost is $8,833 (Table 5). *In fine*, the break-even bunker price point (equation 3) is a function of:

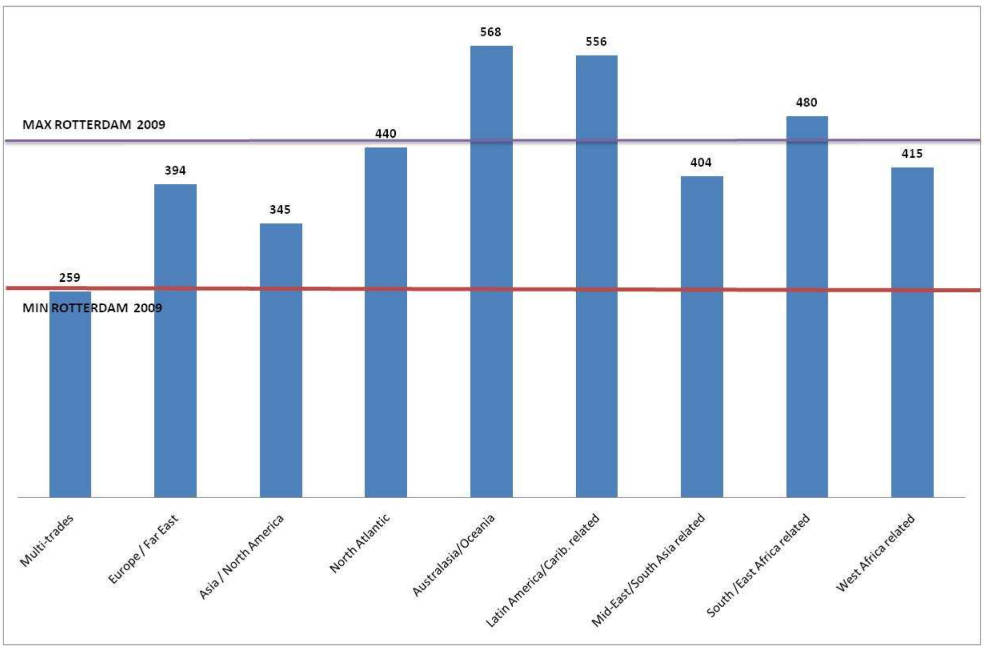
1) Annual savings on consumption, derived from Table 4, which are equal to (56,900,000 - 47,500,000)/(2 x 3.17) = $1,482,000 tons of fuel;

2) Additional operational costs, which are equal to ($8,833 x 365) = $3,224,045 per year per vessel, or $116 million for the 36 additional vessels;

3) In-transit inventory costs for the 64.2% of the 3.2 million TEU that are under slow steaming (Table 3). Of these, approximately 70% are full containers that spend one additional week at sea. These costs are therefore equal to (7 days x $27,331 per TEU x 35%/365)*(64.2% x 3.2 million x 70%) = $266 million.

The bunker break-even price for multi-trade services at which slow steaming would be viable is then equal to [($116 million + $266 million)/1,482,000 tons], or $259 per ton of IFO. Given current bunker prices, this result suggests 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. Figure 1 presents the results for all trades.

Figure 1. Bunker price breakeven point in $/ton



These findings have a number of implications. For instance, 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, with an average of $365.

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 (MEPC 59/4/5, 2009; MEPC 54/9/48, 2009) on bunkers of around $50 could be enough to pass the break-even point, and to maintain reductions in CO_2 emissions over the long run or to ensure additional reductions in these emissions.

5. Conclusions

Slow steaming is a cost-effective way of reducing CO_2 emissions in the short term. This paper shows that slow steaming has reduced emissions by around 11% over the past two years. This is close to the target of a 15% reduction by 2018, which has been proposed by the International Maritime Organization's Marine Environment Protection Committee (MEPC 60/4/36). Furthermore, the reduction can be achieved without the adoption of any new technology.

This result is, to some extent, limited by our assumptions. We assume that slow steaming represents a 30% reduction in the average speed. However, some services are operated either at higher or lower slow steaming speeds, with some vessels operating with a 40% reduction in speed. Even within a service, the speed does not remain constant throughout the year. At the same time, a variety of technical elements were not considered. For example, containerships are built to sail at optimal speeds of 20-22 knots and with load factors of 70-90%. At very slow speeds, additional consumption occurs and the quality of the exhaust is altered. In addition, such slow speeds give rise to design and safety issues (Devanney 2010a, 2010b, 2010c; Faber et al., 2010).

To conclude, the changes in freight rates, bunker prices, operating costs and inventory costs all affect the long-term viability of slow steaming as a means of reducing CO_2 emissions. 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. As freight rates will rise, slow steaming can only remain sustainable in the long term if bunker prices remain high or if powerful market-based solutions, such as tax levies or cap-and-trade systems, are implemented to sustain bunker prices.

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