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Document de Travail

Working Paper

Lemna

EA 4272

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2010/17

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Abstract: This paper estimates the annual CO_2 emissions by international shipping over the 2007-2009 period. Once controlling for the recent changes in activity levels in international trade, we evidence a slow-down of the total volume emitted in 2009. Using an exhaustive dataset of the world fleet, we provide international rankings in CO_2 emissions both by country of ownership and by flag of registry of vessels. We finally study how, through flagging-out, most ship-owners from developed countries are implicitly exporting a share of their CO_2 emissions under foreign flags. This suggests that a system based on taxes or quotas to be applied by vessel type rather than by the country of ownership or flag of registry may be more efficient to reduce CO_2 emissions in shipping.

Keywords: CO2 emissions, international shipping, flagging-out

Submitted: March 2010

1. Introduction

International shipping generated around 2.7% of all worldwide GHG emissions in 2007 compared with 21.3% for road transport and 1.9% for international aviation (IMO report from 2009 - MEPC59/Inf. 10 2009). Therefore, and even if limited, ocean going vessels are contributing to global warming, and technical, economical and legal instruments are under studies to limit their impact (Corbett and Fishbeck 1997, Endersen et al. 2003, 2007, Eyring and al. 2005a, 2005b, 2009)

The recent failure in December 2009 of the last UNFCCC/COP15 illustrates at the same time the difficulty in reaching a global agreement on the best way to deal with CO_2 emissions. The same difficulty exists within the shipping industry (Oberthur 2003) as it is now more than 10 years that the International Maritime Organization (IMO) works on the implementation of a regulatory instrument on GHG air emissions from shipping that should be a) binding to all flag states; b) cost effective; c) practical; d) transparent; e) fraud-free; f) support technical innovation; g) easy to administer; h) and with limited competitive distortion (UNCTAD, 2009).

The difficulties in reaching a multilateral collective agreement at a country level have led negotiations at IMO to move toward a more industrial approach based on the vessel types rather than toward a regulation by countries. In particular, two market-based solutions are under study: an Emission Trading System with quotas allocated by type of vessels (MEPC 60/INF 8. 2009, MEPC 29/4/24 2009); and a system of differentiated taxes on marine fuel (MEPC 59/4/5. 2009, MEPC 54/9/48. 2009).

If the solution focuses on a direct contribution by vessels, countries will however be affected. This impact might even be higher considering that unilateral climate policy will most probably be implemented in a first stage and the new instrument only be ratified by a limited number of countries. It might then lead to a re-location of polluting vessels from regulated to unregulated countries, the so-called risk of *carbon leakage* (Aichel and Felbermayr 2010). In shipping, this would imply the flagging-out of vessels or an increase in the registration of vessels under flags of registry of countries different from the country of ownership.

Given this possibility, it then matters to further study the contributions in CO_2 emissions of countries either apprehended as a flag of registry or as a place of domiciliation of owners and to investigate to which extent, through flagging-out, owners are exporting their emissions under foreign flags. The focus on CO_2 emissions was chosen as it represents around 98% of all GHG emitted in quantity (IMO,

2009) and is the primary vector for climate change and despite the fact that it might be less dangerous than other exhaust gases for human health (Eyring and al., 2009).

For that purpose, we use a data set on more than 40,000 vessels grouped into 49 different types of vessels (Lloyd Register Fairplay database, May 2009) to estimate their emissions in CO_2 for 2007, 2008 and 2009. We then aggregated the results at the country of ownership and at the country of registration levels in absolute (total emissions per country) and relative terms (mean emission per country) to estimate the individual contribution of shipping nations to CO_2 emissions. Our main contribution is to provide for the first time rankings of brown fleet respectively by flag of registration and owner's country and as a final step, to estimate the share of CO_2 emissions implicitly 'exported' and 'imported' by countries under foreign flags.

We found that the absolute contribution of countries is related to the number of vessels registered or controlled in a given country, while their relative contribution to emissions is more affected by their specialization as well as changes in activity levels of ships. For the relative contribution, countries specialized in the registration and ownership of containerships that need to meet regular schedule and therefore to sail at a relatively high speed are the main contributing countries. Estimates also show that these countries are mainly developed countries. From a public policy viewpoint, market-based solutions to reduce pollution could have then harmful consequences in providing incentives for these countries to "export" even more than their vessels under foreign flags.

The remainder of our paper is organized as follows. In section 2, we describe the methodology developed in the IMO (2009) report to estimate CO_2 emission at a vessel level in 2007 and provide an updated estimation considering the latest developments in shipping markets for the years 2008 and 2009. In Section 3, we present aggregated results on rankings in terms of pollution both at the flag of registry and ownership level. We also discuss the relative importance of "imported" and "exported" pollution for each country. Finally, section 4 gives the conclusion.

2. CO_2 emissions in shipping, 2007-2009

2.1. The measurement of CO_2 emissions

The estimation of annual GHG from international shipping has been subject to numerous studies that were synthesized within an IMO study in 2009 (IMO-MEPC59/Inf. 10, 2009, Corbett et al. 2007, Starcrest 2008, Psaraftis et al. 2009, Eide et al. 2009, MEPC 60/INF 8. 2009, MEPC 29/4/24 2009, MEPC 59/4/5. 2009, MEPC 54/9/48. 2009). Focusing on CO_2 emissions, estimates are derived from

estimates on the quantity of fuel burned by a vessel with an emission factor for CO_2 estimated between 3130-3700 kg per ton of fuel burned (IMO 2009).

Annual CO_2 emissions by international shipping are therefore derived from primary data on the total amount of fuel consumed for shipping activities in a year. Two main sources are used for that purpose: either data collected from the bunkering industry (method 1); or data on vessel fuel consumption and activity level (method 2). Hence, for a specific vessel, its annual fuel consumption is estimated according to how much fuel was purchased by this vessel in a year, or knowing its average daily fuel consumption, in multiplying this daily rate by the number of days in a year the vessel is at sea or in port (activity level).

As stated within the IMO study (2009), estimates from these two methodologies are todays reaching very comparable results, approximated to a total amount of 285 million tons of fuel for international shipping in 2007 equivalent to around 885 million tons of CO_2 emissions. In this paper, we base our initial estimates on consensus values on daily fuel consumption and activity level in 2007 proposed by experts of the IMO 2009 study (method 2). This method has the main advantage over method 1 to avoid limitations on statistics available from the bunkering industry with respect to coverage and consistency in reporting and accuracy in various parts of the world.

We then start with a differentiation amongst 63 homogeneous categories of vessels that are identified within the IMO study as operating under similar conditions (for instance the same activity level for all Very Large Crude Carriers) and using similar engine (i.e. the same daily consumption rate). For each category of vessels, we have an estimation of the annual amount of fuel burned per year, from which we deduce the total amount of CO_2 emitted. Then, we rely on an exhaustive dataset from Lloyd's Register Fairplay (LRF, may 2009) on more than 110,000 vessels which includes information on all merchant vessels in the world fleet and in particular for each vessel, its flag of registry and owner's country of domiciliation. A key feature of these data is that they allow us to describe, in comparison with the results presented so far, the situation of the world fleet over the 2007-2009 period at global and at country levels.

In this sample, only vessels under IMO regulations are considered. We focus on the subsample of vessels that are involved in international shipping and that are larger than 400 gross tons. Our sample is then reduced to 42,616 vessels in 2007 (respectively 44,578 in 2008 and 48,006 in 2009), grouped into 49 categories (see Appendix 1 for further details). Since we have information on the characteristics of the vessels, in particular the country of domiciliation of the ship-owner and the flag

of registry of the vessel, we can easily perform international rankings providing either cross-country or cross-flag comparisons.

Although it is clear that the methodology we use in this article to calculate the total volume of CO_2 emissions is not new, we have sought to improve the existing results in the following ways. We provide updated estimations for 2008 and 2009, which are based on changes in activity levels for the 49 main sub-categories of vessels. We account for a correction factor reflecting the brutal slow-down in international trade for those years, which is then multiplied by the corresponding number of vessels within a category (see Appendix 1). To do so, various representative routes and trades have been selected for the various categories of vessels. For instance, the changes in activity level for tankers of a size of more than 200,000 deadweight tons (dwt) or Very Large Crude Carriers (VLCC) have been estimated (Lloyd's Shipping Economist monthly statistics) based on changes in the total export volume of oil carried by these vessels in 2008 in comparison to 2007 (-3.34%) and then during the first 9 months of 2009 in comparison with the first 9 months of 2008 (-3.18%). The slow-down in international trade was then taken into account in considering that the total amount of fuel burned for these vessels in 2008 was 3.34% less than in 2007 and 3.18% less in 2009 than in 2008. For containerships to provide another example, proxy of activity levels for the 6 sub-categories of containerships were assumed to follow the trend observed in the number of containerships sailing to and from Asia. This indicator is more relevant than the number of containers traded as numerous empty containers carried aboard vessels imply that this proxy might be biased. As seen in appendix 1, the slow down in container level activities mainly occur in 2009 (-14.67%) and could be explained by the time needed to reorganize liner shipping services during 2008. However, for 2008, an over-estimation might exist as slow steaming was implemented, which also has an impact on fuel consumption (Wang 2009).

The main advantage of using activity-adjusted activity levels was to capture the effect of the slow-down in activity level due to the recent financial crisis both for 2008 and 2009, an element that was not taken into account in former studies on CO_2 emissions from international shipping.

2.2. CO_2 emissions over the 2007-2009 period

As a preliminary step, we investigated the total amount of CO_2 emitted from international shipping for the years 2007, 2008 and 2009 amongst vessels of more than 400 gt and for an emission factor of 3130 kg of CO_2 emitted/ton of fuel burned. We present our results in Figure 1 in various forms. On the one hand, we respectively consider the total emissions of CO_2 (1A) and the average emissions per vessel (1B). On the other hand, for the sake of comparison, we present our results both under the

assumption of a level of activity in 2008 and 2009 similar than in 2007 (which is the benchmark case taken from the IMO study for 2007), and then for activity-adjusted levels both in 2008 and 2009 (using the correction factor presented in Appendix 1).

Insert Figure 1 around here

According to our results, we found a total amount of CO_2 emitted in 2007, which is estimated at 851 million tons for 2007. This result is slightly lower than the 885 million tons estimated in the IMO study for the same year 2007 (-3.84%). Essentially, it is explained by our choice to restrict our attention to the subsample of vessels above 400 gt, while the IMO study considers all vessels above 100 gt and by an emission factor of 3130 kg of CO_2 emitted which is the lower limit (between 3130 and 3190 according to IPPC 2006) A look at the LRF data indicates that this leads to a difference of around 7,000 vessels out of 42,000. Nevertheless, we choose to focus only on the largest vessels as Annex VI of MARPOL 73/78 ratified in 2005 applies so far only to these categories of vessels.

Assuming first that the same level of activity observed in 2007 applies in 2008 and 2009, the increase in the number and type of vessels in the world fleet since 2007 is the only factor explaining the increase in the total amount of CO_2 emitted, from 851 million tons to 1026 million tons in 2009 (Figure 1A – Benchmark). The total increase of 20.6% over the last 2 years may be decomposed as an increase of 7.9% from 2007 to 2008 and of 11.8% from 2008 to 2009. Over the same period, the number of vessels has increased by 4.6% from 2007 to 2008 and 7.7% from 2008 to 2009. A similar pattern is observed when considering the average amount of emission per vessel, which increases from 0.02 million tons of CO_2 in 2007 to 0.0214 in 2009. This is evidence of a higher increase in the world fleet of vessels which are on average emitting more CO2 (Figure 1B – Benchmark).

The activity-adjusted level estimates provide a slightly different and better picture since they account not only for the increase in the number of vessels per category, but also for the slow down in activity level since mid-2008 and for the first 6 months of 2009 (Appendix 1). Due to the increase in the number of vessels delivered in particular in the beginning of 2008, the volume of CO_2 emissions increases by 10.0% from 2007 to 2008 and 6.1% from 2008 to 2009 (Figure 1A – Activity-adjusted). This leads to a reduction of 3.9 points of percentage over the total period when turning to the activity adjusted levels. At the same time, activity-adjusted results at the vessel level (Figure 1B – Activity-adjusted) show a slight decrease in the average CO_2 emissions by vessel, from 0.021 in 2008 to 0.0207 for 2009. This pattern is explained by a reduction in the activity level that offsets the impact of the increase in the world fleet.

Since the LRF data include information about the vessels' characteristics, it is straightforward to identify the type of vessels which are emitting the most. Figure 2 provides an analysis for the various categories of vessels. In line with the IMO study for 2007, we found that vessels associated with the highest proportion of CO_2 emissions are containerships and tankers, around 240 million tons each out of 850, followed by bulkers with around 180 million tons (Figure 2A – activity-adjusted). Of course, these results are directly proportional to the amount of fuel burned by these vessels in a year and by the number of vessels of each type.

Insert Figure 2 around here

To control the latter effect, we turn to an analysis at the vessel level (Figure 1B – activity-adjusted). We found interesting differences between containerships and both tankers and bulkers. For the latter, their total contribution to CO_2 emissions is due to a high number of vessels (around 25% of the world fleet for tankers and 15% for bulkers of the world fleet in 2009). Conversely, the contribution per vessel remains low, around 0.02 for both tankers and bulkers as depicted in Figure 2B. For containerships, their high contribution is due to the high emission rate by vessel (around 0.06 per year versus 0.02 on average for the world fleet) rather than by the number of vessels. They represent around 9% of the world fleet.

Three main interrelated explanations for the high emission rates of containerships exist. Firstly, these vessels are operated under high activity level since liner shipping services require high rotation rates. Secondly, in order to achieve these high rotations in services, containerships need to use powerful two-stroke engines with high fuel consumption rates, and more specifically for larger vessels. Finally, due to the delivery of large containerships during 2008, this trend is reinforced for that year. A reverse trend is observed in 2009 as the slow-down in deliveries of new containerships and in activity levels tend to reduce their emissions in CO_2.

To summarize, our results highlight the importance of CO_2 emissions in international shipping. These emissions have been curbed since 2008 given the recent slow-down observed in maritime transportation in 2008 and 2009. Containerships and tankers are the main contributors in absolute terms, while containerships are by far the main contributors in relative value. In the next section, we further disentangle the role of the size of the fleet and the type of vessel when studying CO_2 emissions respectively by country of ownership and by flag of registry.

3. CO_2 emissions by country of ownership and flag of registry

3.1. A ranking of brown owners and brown flags

We now assess the contribution in CO_2 emissions respectively by country of ownership and by countries where the vessel is registered (flag of registry). Information was retrieved for each vessel involved in international shipping from the LRF database (May 2009). We describe the top-40 fleet in terms of country of ownership in Table 1A and in terms of flag of registry in Table 1B.

Insert Table 1A around here

Insert Table 1B around here

Table 1A highlights Japan as the leading shipping nation in number of vessels, with 11.6% of the world fleet controlled in 2009 (5550 vessels). It is followed by China (8.4% and 4010 vessels), Germany (8.1% and 3888 vessels) and Greece (5.8% and 2807 vessels). The ten most important countries represent 53.3% of the total merchant fleet in 2009 (25,594 over 48,006 vessels). These countries, respectively Japan, China, Germany, Greece, Indonesia, Russia, Norway, South Korea, Turkey, Panama and United States of America are all controlling more than 1000 vessels in 2007. We note a slight increase in the share of countries located in Asia over the period since Hong Kong and Singapore in 2008 and Vietnam in 2009 are joining the group of countries with more than 1000 vessels.

In terms of flag of registry (Table 1B), Panama is the first flag with around 14.8% of all vessels involved in international shipping in 2009 (7,106 vessels). It is followed by China (5.3% and 2,531 vessels) and Liberia (5.3% and 2,522 vessels). Concentration by flag is less pronounced than by country of ownership, since the 10 most important flags represent 48.9% of the total fleet (23459 over 48,006 vessels). These flags are Panama, China, Liberia, Japan, Indonesia, Malta, Singapore, Hong Kong, Marshall Islands and Antigua. The comparison is of interest. Only China, Indonesia, Japan and Panama are in the top ten rankings by flag of registry and by country of ownership. Germany has for instance the 3rd rank in terms of ownership, but this country is only at the 26th rank as flag of registry.

Together with the size of the fleet, earlier discussions point out the role played by the specialization of the fleet in understanding the volume of CO_2 generated by a country. In Tables 2A and 2B, we describe respectively by countries of ownership and of registry the distribution of their fleet by type of vessels.

Insert Table 2A around here

Insert Table 2B around here

In terms of ownership, Japan and Greece present similar features with a predominance of bulkers (28.8% and 26.7% respectively in 2009) and tankers (31.4% and 21.6%). Germany, due to a specific financing scheme known as KG that provides tax exemptions for investors, is largely specialized in containerships (47.9% of its fleet in 2009), while Indonesia and Russian ship-owners are mainly active in the dry cargo sector with respectively 51% and 54.3% of their fleet (and to a less extent Turkey with 47.8%). Chinese ship-owners are operating on the three main bulk markets from dry bulk (26.7%), dry cargo (36.6%) to liquid bulk (21.6% for tankers). South Korea and Norway have more tankers on average in their fleet (33.9% and 33.4% respectively in 2009), while the situation is more heterogeneous in Panama.

For the specialization of the top flags of registry (Table 2B), differences in the fleet structure also exist. For instance, Panama is specialized in the registration of bulkers (34.3% compared to 18.1% in the world fleet in 2009), while Liberia records a high proportion of containerships (33.8% compared to 10.9%). Finally, for countries that are at the same time major ship-owning countries, similarities exist between ownership and flag specializations. Examples here are for instance Germany with 63.9% of containerships in 2009 or Singapore with 56.6% of tankers.

In Tables 3A and 3B, we begin with a ranking of the most emitting countries of ownership in CO_2 in 2007, 2008 and 2009. We first calculated the total contribution of each country to CO_2 emissions from international shipping and then controlled the size of the fleet in calculating the mean contribution per vessel. It should be noted that we only present in our rankings countries with a fleet of more than 50 vessels.

Insert Table 3A around here

Insert Table 3B around here

According to our estimates, Germany is the first emitting country of ownership. These emissions represent about 12.5% in 2007, 13.5% in 2008 and 13.1% of all CO_2 emissions in volume. The second country is Japan (with 12-12.9% of total emissions), followed by Greece (8.1-8.6%), China (7.3-7.6%) and Panama (4.1-4.2%). We do not observe any changes in the top five countries over the period. A few examples clearly show that the size of the fleet is not the only factor influencing the rankings. For

instance, Indonesia has the 5th most important fleet in terms of number of vessels in 2009, but it contributes to only 1.2% of all emissions (21st rank in 2009 due to vessels of relatively small size).

Conversely, Denmark is at the 18th rank with respect to the number of vessels in 2009, but it is at the 7th rank amongst the brownest countries, with a contribution of 3% to total CO_2 emissions. Denmark is in particular specialized in containerships with the first shipping line in the world being Danish (Maersk Line). It also has the feature to control large containerships, which are the ones emitting the most within the containership category. Differences in rankings are therefore explained by the specialization of the fleet and, within each category, by the size of vessels (Table 3B). In that scenario, Israel, France, Bermuda, Taiwan and Denmark are the first 5 emitting countries over the three years under consideration.

For the ease of interpretation, we choose to represent in Figure 3 the rankings associated to both the total and mean CO_2 emissions by countries of ownership, with a focus on fleets with more than 150 vessels. This allowed us to account for the composition of the fleet as well as changes in activity levels over time. When a country is located on the first bisector line (or close to), its ranking in terms of total emissions and per vessel emissions are similar. Countries located below the first bisector line are emitting relatively more due to high emission rates and/or activity levels, while the reverse pattern holds for countries over the first bisector line.

Insert Figure 3 around here

According to our data, we found that in 2007 that Bermuda, France, Canada, Bahamas, Cyprus, Belgium, Iran, Spain, Finland or Nigeria are the worst countries when considering their rankings per vessel compared with their ranking on total emissions. However, the reasons differ according to the country considered. For instance, for Bahamas and Cyprus ship-owners, it is mainly explained by an over-representation of large tankers in their fleet (45% and 32.7% respectively in 2009), while for countries like France and Canada it is more the presence of many containerships and passenger/ferry vessels that explains this situation.

There are a few differences over the three years. The relative position of Taiwan deteriorated for instance from 2007 to 2009 because of an increase in the number of large tankers (+14.4% over the period). Conversely, a country like Japan, which is the first country of ownership and is specialized in bulk carriers, has a much better position in terms of emissions per vessel than in total emissions. The same applies for South Korea, China, Italy, Norway, Turkey, Russia or Indonesia that have the

particularity to be either specialized in less emitting vessels like Japan or in vessels with a relatively smaller size like Indonesia.

Insert Table 4A around here

Insert Table 4B around here

We then carried out a similar analysis applied to flags of registry (Tables 4A and 4B and Figure 3). As expected, Panama is the most important country in terms of CO_2 emissions with 20.3% of all emissions in 2009, followed by Liberia (10.9%) and Marshall Islands (5.0%). We observed some changes in the top five countries since China moved from the 3rd most emitting countries in 2007 with 4.2% of all emissions to the 7th rank in 2009 (but with a very similar percentage of 4.1%). There are hence flags which have increased their position (or worsened their situation). This is for instance the case of Marshall Islands, moving from the 5th position in 2007 to the 3rd position in 2009 with an additional emission of +0.6 point of percentage between 2008 and 2009, or Hong Kong (from 7th to 5th). In both cases, the increase in the registration of tankers (+4.9% and +6.2% respectively from 2007 to 2009) is the main factor explaining this evolution.

In terms of emission per vessel (Table 4B), the ranking shows higher emission rates for flags with more tankers or containerships in their fleet (or both). This is for instance the case for Bermuda, France and Germany. Finally, results in Figure 3 by flag of registry show the relatively bad performance of flags specialized in the registration of one emitting vessel type or of many combinations of emitting vessels. This is in particular the case for the German flag of registry which includes a large proportion of containerships as mentioned earlier and with the Danish International Register and the United Kingdom with a relative over-representation of containerships and tankers.

To conclude, our estimates illustrate one of the main features of the shipping industry. Developed countries are controlling vessels that are emitting the highest volume of CO_2. The main reason is the high capital investment needed for operating containerized liner services when ship-owners from developing countries might not have access to the capital required. The next section shows how through flagging-out, emitting countries are 'exporting' a share of their emissions under flags of foreign countries.

4.2. 'Exported' emissions through flagging-out

The comparison between the two sets of ranking described in Figure 3, i.e. by country of ownership and by flag of registry, suggests that there are very different situations amongst countries. A few

examples should be considered. Germany is above the first bissectrice in the ranking by country of ownership, but it is below the bissectrice with the ranking by flag of registry. A very similar pattern is found for United Kingdom. Conversely, Panama is on the first bissectrice with the ranking by country, but its position is above the bissectrice with the flag of registry. This is also the case with Italy. Explaining these changes of relative position is straightforward. It simply means that both the size and composition of the fleet are different at either the country or the flag level.

In what follows, we calculate the weight of what we call respectively 'exported' and 'imported' CO2 emissions. By 'exported' pollution, we mean the total CO_2 emissions from vessels owned by a specific country, but registered under a different flag. Conversely, 'imported' emissions are defined as the contribution in terms of CO_2 emissions generated by vessels from countries different than the flag considered. It should be noted that our definition of CO_2 'exports' and 'imports' remains virtual in the sense that we do not focus on where emissions are generated, but strictly on the country of ownership of the emissions.

For each country of ownership, we decomposed CO_2 emissions in the following way. Starting with the total amount of CO_2 emissions, we calculated a first component defined as owned pollution, i.e. emissions from vessels owned by a country and registered under the same flag. Recalling that Germany, Japan, Greece, China and Panama are the most polluting fleet by country of ownership (without taking flagging-out into consideration), we found a different ranking in terms of owned pollution. The more emitting fleets are then China with 40.75 million tons, followed by Germany, Greece, Panama and Japan. So, the top five are unchanged, but the figures are strongly affected. As reported in Table 5, the amount of owned emissions is much lower than the amount of total emissions. It is for instance divided by 4.5 in Germany and by more than 6 in Japan.

In some cases, there are large discrepancies between total and owned pollution. This is in particular the case of Denmark. Vessels owned by that country generate a total volume of CO_2 emissions of 32.11 million tons, but only about 1 million tons stem from vessels registered under a Danish flag (either Denmark or Danish International Register). Very similar results are found for Taiwan (at the 28^{th} rank in terms of owned pollution), Bermuda (40^{th}) or France (31^{th}). All these countries are characterized by a very limited quantity of owned pollution.

Insert Table 5 around here

The discrepancy between total and owned emissions corresponds to CO_2 emissions 'exported' through flagging-out. In Germany, emissions of 'exported' CO_2 amount to 105.75 million tons (2nd rank), while a slightly higher quantity is exported by Japanese ship-owners (107.07 million tons). These exports represent around 80% of the total volume of emissions owned by German and Japanese ship-owners respectively. The situation is even worse for Bermuda and Denmark, respectively at the 1st and 2nd relative 'exporting' ranks (calculated from the ratio of CO2 exported over total pollution). More than 95% of their total CO_2 emissions are for vessels registered under a different flag. Taiwan (3rd rank), the United Arab Emirates (4th rank) and France (5th rank) are also countries characterized by a very high export ratio. At the opposite, Vietnam, Thailand, Philippines and India (all Asian countries) export less than 20% of their total CO_2 emissions.

The same calculations can be performed when considering 'imported' pollution. By definition, a flag whose vessels are owned by foreign ship owners will be concerned with 'importation' of CO2 emissions, especially when foreign vessels flying its flag are high emitters. From Table 5, we note that Panama and Liberia are the largest countries of 'imported' CO_2 emissions, with respectively 171.93 million tons and 108.18 million tons, which is in line with their status of main flags of convenience. In absolute value (total volume imported), the Marshall Islands (3rd rank), the Bahamas (4th rank) and Singapore (5th) also import a significant quantity of CO_2. Smaller countries are less concerned, for instance Switzerland (40rd rank), Croatia (37th), Ukraine (38th) and Iran (39th).

In terms of relative ranking (ratio of imported emissions over total emissions), Liberia is at the 1st rank. This country imports more than 8 times its owned CO_2 pollution. It is followed by Bahamas (2nd rank and a ratio of 492.6%), Panama (3rd rank and a ratio of 413.1%), Marshall Islands (4rd rank and 384.2%) and Cyprus (5th rank and 176.9%).

Finally, we determined what we call net pollution, defined as the sum of owned plus imported minus exported emissions. Again, this has to be understood as a fictitious amount since the value may be negative if a country exports much more than it imports. It can be seen as a proxy based on CO_2 emissions on which country are gaining, and which country are losing in the process of flagging-in and -out in terms of CO_2 emissions. As expected, the countries that will lose the most are the main flags of convenience with a net emission balance of 186.6 million tons of CO2 for Panama, 100.4 for Liberia, 41.6 for Marshall Islands and 41.2 for Bahamas in 2009. The countries that are winning are Japan (-86.9 million tons in 2009), Germany (-74.9), Denmark (-29.5), Taiwan (-20.9) and Norway (-12.5).

To conclude, this analysis clearly identifies various groups of countries, with diverging interests: on the one hand, countries which are major countries as flag of registry (Panama, Liberia for instance) and for which an allocation of CO_2 quotas would be clearly to their disadvantage; on the other hand, major ship-owner countries (Japan, Germany) for which an allocation of quotas according to the country of domiciliation of owners would be to their detriment. Another result is is that through flagging-in and –out, many countries are rather neutral between the two solutions. For instance, for 15 countries out of the 40 considered in this study, the net emission balance is between -5 and +5 million tons of CO2. Belgium (+0.03 million tons in 2009), Sweden (+0.34) or South Korea (-0.23) are such examples.

Section 4. Conclusions

The identification of targets and taxes to be allocated according to the total or mean CO_2 emissions is a sensitive issue as it has an impact on many countries. The reasons are that the traditional argument (Milles and Waite 2009) according to which rather poor countries use less advanced technology and are polluting more on average does not hold in shipping. Indeed, as shown in this study, these are rather developed countries that are controlling the most emitting vessels (containerships) such as Germany or Denmark. How the quotas are allocated will hence have an impact on the competitive situation of countries.

To avoid undesirable effects that might lead to reluctance from countries, IMO seems to favor today an approach through quotas or taxes based more on the vessel type rather than on the country of registration or flag of registry (MEPC 59/4/5; MEPC 54/9/48.). If this approach as the merit of being more politically neutral, it would not be without effect at a country level. As shown in this article, it will still have an effect on countries depending on the composition of their fleet. If this option was to be chosen, then our results that German ship-owners (13.1% of all CO_2 emissions in volume in 2009), followed by Japanese (12.9%), Greek (8.6%) and Chinese (7.6%) ship-owners would be the first four contributing countries to a fund to be invested in greener technologies.

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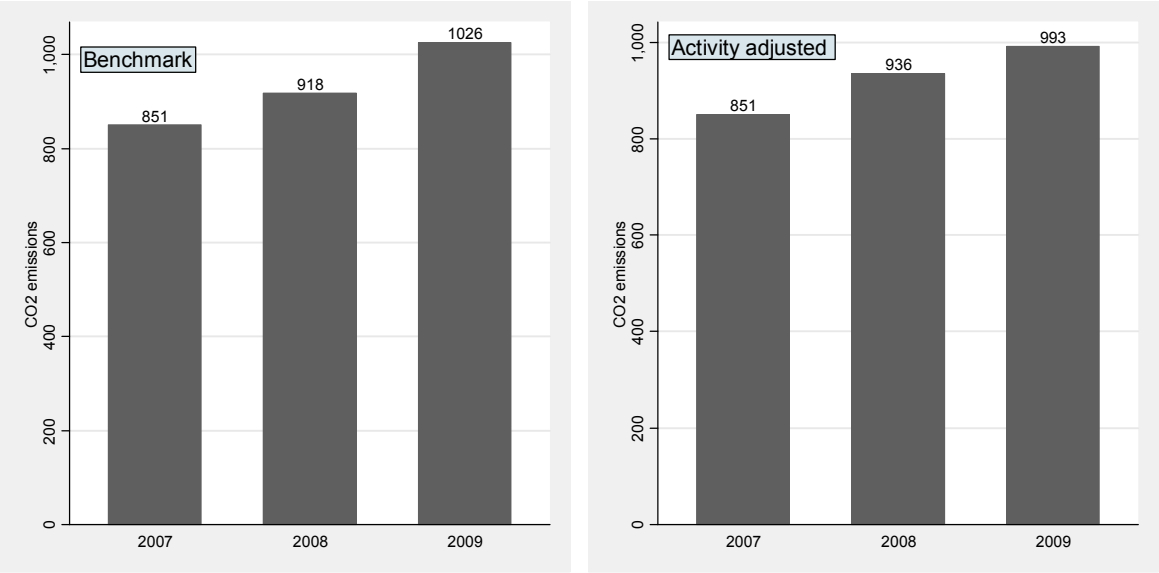
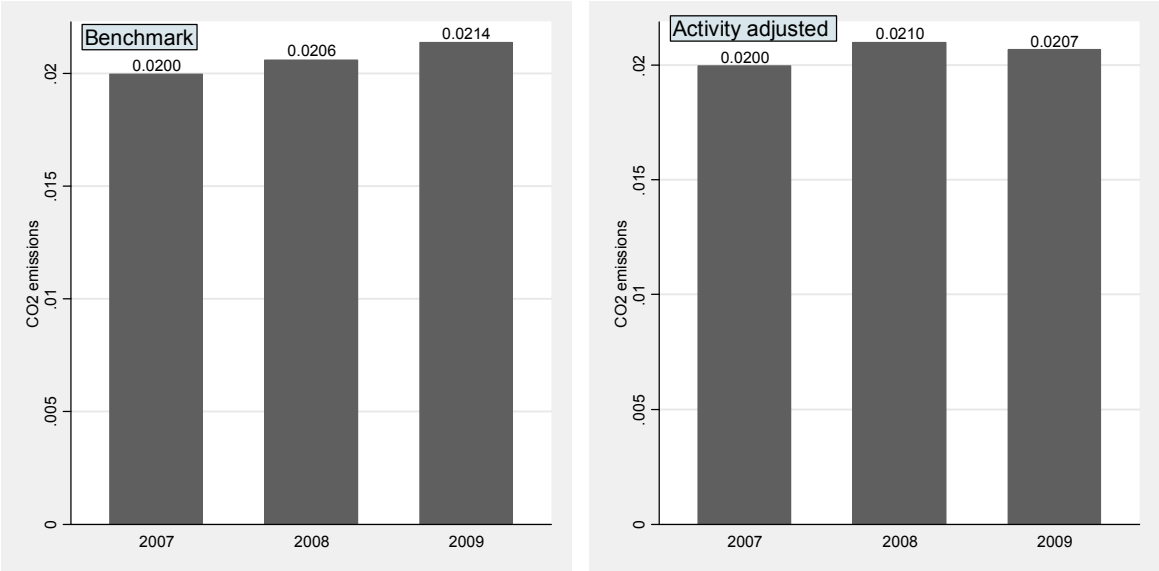
Figure 1. Evolution of CO_2 emissions from 2007-2009

A. Total emissions



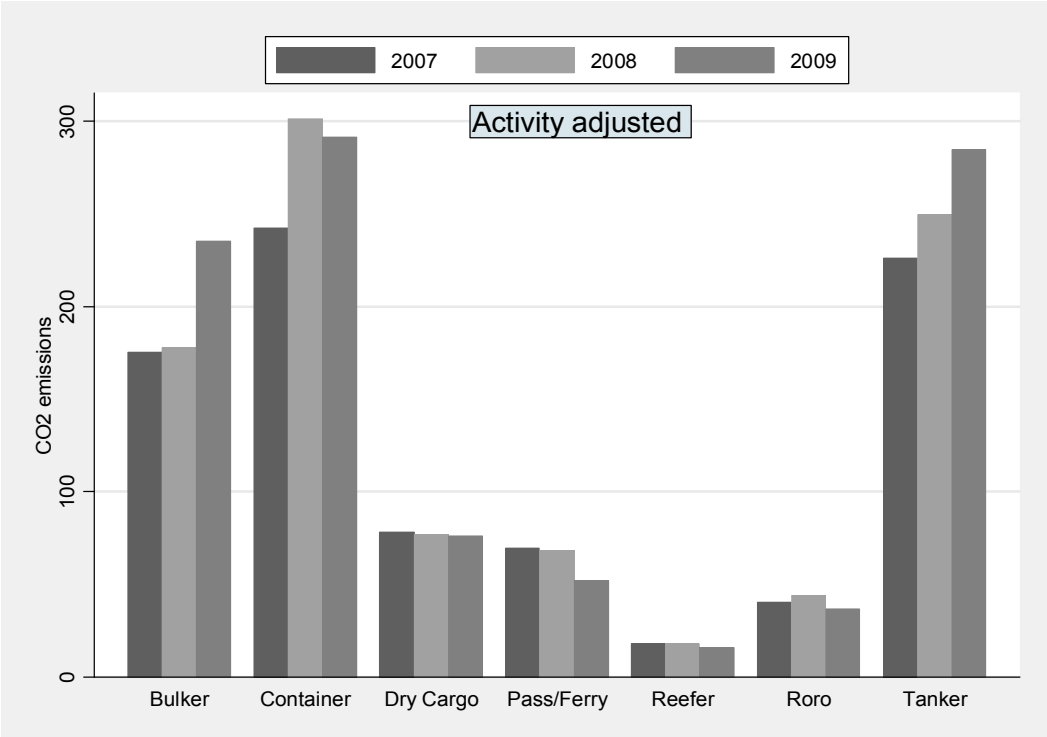
B. Mean emission per vessel



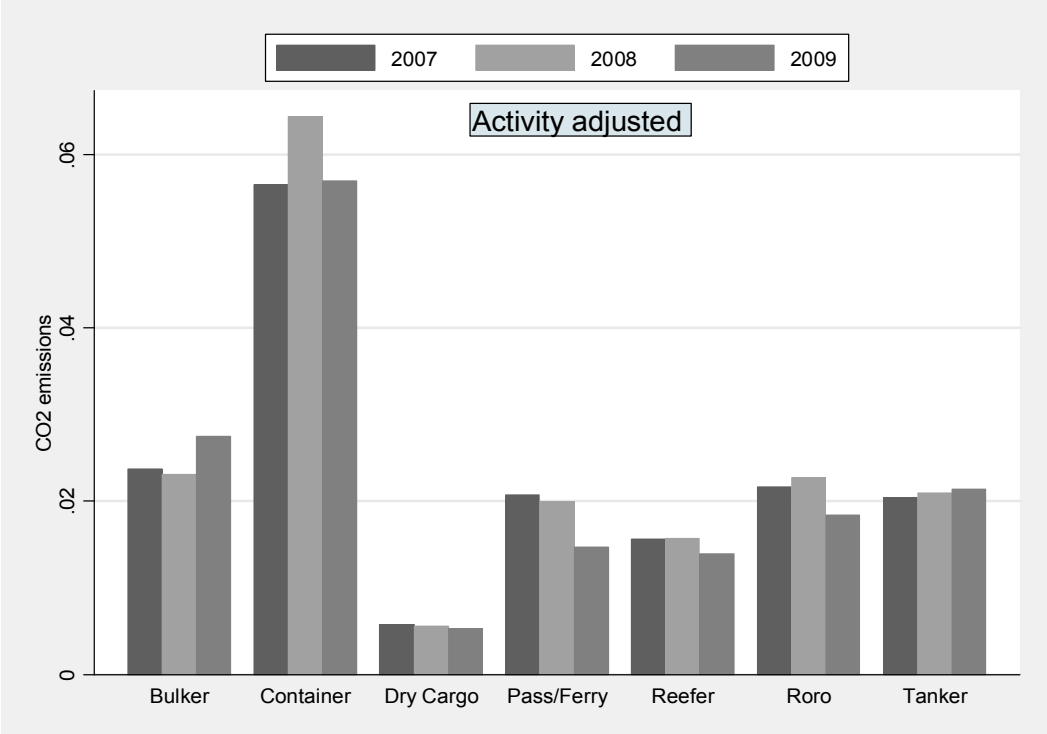
Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Figure 2. Evolution in CO_2 emissions from 2007-2009 per vessel type

A. Total emissions



B. Mean emission per vessel



Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Table 1A. Commercial fleet by country of ownership (top 40) in 2007, 2008 and 2009 (in number of vessels N)

Country of ownership (by rank of importance in 2007)	2007		2008		2009	
	N	%	N	%	N	%
Japan	4830	11.3	5245	11.8	5550	11.6
China	3615	8.5	3732	8.4	4010	8.4
Germany	3078	7.2	3367	7.6	3888	8.1
Greece	2502	5.9	2573	5.8	2807	5.8
Indonesia	1683	3.9	1707	3.8	1721	3.6
Russia	1491	3.5	1508	3.4	1552	3.2
Norway	1418	3.3	1491	3.3	1577	3.3
Korea (South)	1375	3.2	1461	3.3	1577	3.3
Turkey	1371	3.2	1468	3.3	1634	3.4
Panama	1159	2.7	1196	2.7	1278	2.7
United States of America	1113	2.6	1104	2.5	1118	2.3
Hong Kong	954	2.2	1033	2.3	1176	2.4
Singapore	927	2.2	1009	2.3	1109	2.3
United Kingdom	851	2.0	891	2.0	966	2.0
Vietnam	850	2.0	909	2.0	1028	2.1
Italy	811	1.9	864	1.9	958	2.0
Denmark	719	1.7	785	1.8	862	1.8
Netherlands	663	1.6	729	1.6	865	1.8
Taiwan	659	1.5	676	1.5	701	1.5
India	637	1.5	644	1.4	651	1.4
Thailand	599	1.4	601	1.3	605	1.3
Philippines	563	1.3	564	1.3	574	1.2
United Arab Emirates	521	1.2	533	1.2	550	1.1
Liberia	424	1.0	436	1.0	475	1.0
Malaysia	409	1.0	423	0.9	456	0.9
Marshall Islands	401	0.9	413	0.9	450	0.9
Ukraine	397	0.9	399	0.9	406	0.8
Cyprus	342	0.8	372	0.8	444	0.9
Bermuda	319	0.7	336	0.8	372	0.8
Sweden	319	0.7	329	0.7	346	0.7
Syria	298	0.7	297	0.7	292	0.6
Canada	287	0.7	297	0.7	330	0.7
France	247	0.6	265	0.6	304	0.6
Bahamas	237	0.6	251	0.6	282	0.6
Iran	229	0.5	265	0.6	284	0.6
Spain	227	0.5	241	0.5	243	0.5
Belgium	190	0.4	198	0.4	230	0.5
Bangladesh	177	0.4	177	0.4	177	0.4
Nigeria	169	0.4	169	0.4	169	0.4
Others/unknown	5555	13.0	5620	12.6	5989	12.5
Total	42616	100.0	44578	100.0	48006	100.0

Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Table 1B. Commercial fleet by flag or registry (top 40) in 2007, 2008 and 2009 (in number of vessels)

Flag of registry (by rank of importance in 2007)	2007		2008		2009	
	N	%	N	%	N	%
Panama	6261	14.7	6658	14.9	7106	14.8
China	2305	5.4	2362	5.3	2531	5.3
Japan	2206	5.2	2289	5.1	2355	4.9
Liberia	2056	4.8	2204	4.9	2522	5.3
Indonesia	1636	3.8	1656	3.7	1665	3.5
Malta	1357	3.2	1456	3.3	1608	3.3
Singapore	1171	2.7	1339	3.0	1536	3.2
Russia	1168	2.7	1176	2.6	1199	2.5
Hong Kong	1078	2.5	1218	2.7	1439	3.0
Bahamas	1074	2.5	1137	2.6	1235	2.6
Greece	1063	2.5	1089	2.4	1224	2.5
Antigua	1037	2.4	1141	2.6	1307	2.7
Korea (South)	1022	2.4	1053	2.4	1106	2.3
Marshall Islands	1004	2.4	1132	2.5	1390	2.9
Turkey	788	1.8	826	1.9	956	2.0
Vietnam	769	1.8	828	1.9	953	2.0
Cyprus	761	1.8	829	1.9	1008	2.1
Cambodia	727	1.7	723	1.6	707	1.5
Philippines	673	1.6	678	1.5	686	1.4
Italy	666	1.6	704	1.6	781	1.6
Netherlands	613	1.4	679	1.5	805	1.7
Thailand	589	1.4	586	1.3	589	1.2
India	576	1.4	588	1.3	609	1.3
St Vincent	569	1.3	552	1.2	541	1.1
United Kingdom	525	1.2	586	1.3	632	1.3
United States of America	502	1.2	498	1.1	506	1.1
Germany	480	1.1	502	1.1	579	1.2
Norwegian International Register	439	1.0	463	1.0	491	1.0
Malaysia	395	0.9	408	0.9	443	0.9
Norway	332	0.8	340	0.8	363	0.8
Danish International Register	291	0.7	312	0.7	336	0.7
Honduras	279	0.7	279	0.6	278	0.6
Isle of Man	254	0.6	272	0.6	304	0.6
Sierra Leone	248	0.6	247	0.6	244	0.5
St Kitts& Nevis	231	0.5	218	0.5	198	0.4
Belize	230	0.5	230	0.5	233	0.5
Gibraltar	225	0.5	241	0.5	289	0.6
Ukraine	217	0.5	215	0.5	214	0.4
Georgia	203	0.5	198	0.4	195	0.4
Others	6596	15.5	6666	15.0	6843	14.3
Total	42616	100.0	44578	100.0	48006	100.0

Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Table 2A. Fleet structure in 2009 by country of ownership (top 40)

Country of ownership	Bulker	Container	Dry Cargo	Pass/Ferry	Reefer	Roro	Tanker
Japan	28.8	6.6	18.5	4.8	1.8	8.1	31.4
China	26.7	8.5	36.6	3.0	2.4	1.2	21.6
Germany	7.6	47.9	28.3	1.8	0.7	1.4	12.2
Greece	34.1	6.7	7.8	9.5	1.7	3.5	36.7
Indonesia	6.6	5.7	51.0	12.4	0.2	1.0	23.2
Turkey	12.9	4.6	47.8	7.6	0.1	2.0	24.9
Korea (South)	25.2	8.3	24.1	4.2	2.0	2.3	33.9
Norway	10.3	1.7	22.6	14.3	8.2	9.4	33.4
Russia	6.6	2.3	54.3	1.4	5.7	2.0	27.5
Panama	18.6	17.8	27.0	9.9	2.7	4.5	19.4
Hong Kong	31.4	8.4	23.9	5.8	0.9	4.6	25.1
United States of America	15.2	6.8	15.7	18.8	2.5	9.8	31.1
Singapore	11.9	15.9	11.5	2.1	0.8	2.4	55.5
Vietnam	10.4	2.5	76.7	0.4	0.4	0.3	9.3
United Kingdom	21.0	9.2	22.6	8.5	1.1	5.9	31.7
Italy	12.0	1.7	11.2	23.1	0.6	8.4	43.1
Netherlands	3.0	9.9	53.9	2.8	9.5	4.7	16.2
Denmark	9.7	27.5	19.3	5.6	0.8	5.2	31.9
Taiwan	33.5	29.7	17.7	1.1	3.6	1.7	12.7
India	20.3	1.7	46.7	6.6	0.0	0.5	24.3
Thailand	9.1	6.8	25.5	3.5	5.5	0.3	49.4
Philippines	4.7	0.7	40.8	22.0	4.2	3.3	24.4
United Arab Emirates	10.5	10.0	23.5	2.2	0.5	8.0	45.3
Liberia	39.2	2.9	6.1	2.3	7.8	2.3	39.4
Malaysia	1.5	11.0	32.2	8.3	0.0	1.5	45.4
Marshall Islands	48.7	9.1	18.0	0.9	0.9	1.1	21.3
Cyprus	18.9	17.3	21.2	4.1	2.5	3.4	32.7
Ukraine	6.9	0.7	70.7	3.9	6.4	2.7	8.1
Bermuda	25.0	4.6	6.5	0.8	4.0	12.1	47.0
Sweden	1.7	0.3	14.7	13.0	3.8	19.1	47.4
Canada	34.8	15.2	8.5	29.1	0.0	3.0	9.4
France	7.2	38.2	4.6	23.4	0.0	5.6	21.1
Syria	17.8	1.4	78.4	0.0	0.3	1.4	0.7
Iran	23.6	10.6	35.9	3.5	0.7	1.4	24.3
Bahamas	19.1	0.0	16.3	10.6	2.1	6.7	45.0
Spain	10.7	6.6	11.9	28.0	5.3	8.6	28.8
Belgium	17.0	6.5	21.3	1.7	5.7	11.3	36.5
Bangladesh	2.8	4.0	48.0	0.6	0.0	0.6	44.1
Nigeria	1.8	0.0	4.7	2.4	0.0	1.8	88.8
Finland	1.2	1.9	28.6	29.8	0.0	24.2	14.3
All	18.1	10.9	29.4	7.3	2.3	4.2	27.8

Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Table 2B. Fleet structure in 2009 by flag of Registry (top 40)

Flag of registry	Bulker	Container	Dry Cargo	Pass/Ferry	Reefer	Roro	Tanker
Panama	34.3	11.6	18.2	2.0	3.6	6.7	23.6
China	22.2	7.6	34.3	5.1	2.4	1.5	26.9
Liberia	19.0	33.8	4.2	0.1	4.3	2.2	36.4
Japan	15.4	0.9	32.2	10.6	0.1	5.7	35.1
Indonesia	6.1	5.8	54.0	12.8	0.2	1.1	20.1
Malta	32.6	5.8	25.1	3.5	1.7	3.5	27.6
Singapore	13.3	20.4	4.4	0.6	0.3	4.5	56.6
Hong Kong	42.5	18.3	9.8	6.0	0.0	1.2	22.2
Marshall Islands	29.2	15.5	5.7	0.6	1.1	1.6	46.3
Antigua	4.8	32.8	58.3	0.0	0.8	1.8	1.4
Bahamas	21.2	4.9	11.3	11.5	9.8	7.7	33.6
Greece	25.7	3.5	7.6	19.6	0.1	1.8	41.7
Russia	5.0	1.1	56.1	1.8	6.0	1.8	27.9
Korea (South)	22.7	7.2	27.3	5.1	1.2	1.9	34.6
Cyprus	31.0	23.3	21.6	3.0	1.0	2.7	17.5
Turkey	11.3	4.7	43.8	12.2	0.1	3.0	24.8
Vietnam	7.0	2.1	80.5	0.4	0.4	0.2	9.3
Netherlands	0.5	10.3	61.6	4.6	1.2	3.7	18.0
Italy	10.5	2.7	7.7	30.1	0.5	8.3	40.2
Cambodia	7.5	1.0	83.7	1.0	3.0	0.3	3.5
Philippines	12.5	1.2	38.6	17.9	3.8	3.6	22.3
United Kingdom	5.9	34.0	13.4	16.5	1.3	8.5	20.4
India	17.7	2.5	47.9	6.7	0.0	0.3	24.8
Thailand	7.8	3.7	26.1	3.9	5.3	0.0	53.1
Germany	3.5	63.9	12.6	8.3	0.2	2.8	8.8
St Vincent	14.2	3.7	61.0	4.8	3.1	6.3	6.8
United States of America	9.9	17.4	10.9	26.5	0.8	16.4	18.2
Norwegian International Register	11.6	0.2	12.2	0.6	2.0	14.5	58.9
Malaysia	2.9	9.9	32.1	4.1	0.0	2.3	48.8
Norway	0.8	0.0	25.1	59.2	1.1	5.2	8.5
Danish International Register	2.1	25.0	20.2	5.4	2.1	3.9	41.4
Isle of Man	11.8	3.9	19.1	0.7	1.0	3.9	59.5
Gibraltar	1.4	17.0	51.9	0.0	0.0	2.4	27.3
Honduras	6.1	0.4	52.2	7.6	2.9	3.2	27.7
Sierra Leone	2.5	1.6	76.6	4.5	2.0	2.0	10.7
Belize	12.9	0.0	63.1	1.7	10.7	3.4	8.2
Ukraine	2.3	1.4	69.2	6.5	5.1	2.3	12.1
Canada	33.8	1.0	4.3	44.4	0.0	1.9	14.5
Sweden	2.5	2.5	9.5	22.1	0.0	29.6	33.7
St Kitts & Nevis	7.6	1.0	61.1	3.0	4.0	1.0	22.2
All	18.1	10.9	29.4	7.3	2.3	4.2	27.8

Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Table 3A. Top 40 countries of ownership in total CO_2 emissions (activity adjusted) - Fleets of more than 50 vessels

Rank	2007			2008			2009		
	Country of ownership	% of emissions	cumul	Country of ownership	% of emissions	cumul	Country of ownership	% of emissions	cumul
1	Germany	12.5	12.5	Germany	13.5	13.5	Germany	13.1	13.1
2	Japan	12.0	24.5	Japan	12.7	26.2	Japan	12.9	26.0
3	Greece	8.6	33.2	Greece	8.1	34.3	Greece	8.4	34.4
4	China	7.5	40.7	China	7.3	41.5	China	7.6	42.0
5	Panama	4.1	44.8	Panama	4.2	45.8	Panama	4.1	46.1
6	United States of America	3.3	48.1	Denmark	3.4	49.2	Korea (South)	3.2	49.3
7	Denmark	3.1	51.2	Korea (South)	3.0	52.2	Denmark	3.0	52.3
8	Taiwan	2.9	54.1	United States of America	3.0	55.3	Hong Kong	2.9	55.3
9	Korea (South)	2.9	57.0	Taiwan	2.9	58.1	United Kingdom	2.8	58.1
10	Norway	2.7	59.7	Hong Kong	2.7	60.8	United States of America	2.8	60.8
11	United Kingdom	2.7	62.4	United Kingdom	2.7	63.5	Taiwan	2.6	63.5
12	Hong Kong	2.6	65.0	Norway	2.6	66.1	Norway	2.5	66.0
13	Singapore	2.4	67.4	Singapore	2.5	68.6	Singapore	2.4	68.4
14	Italy	2.0	69.4	Italy	1.9	70.5	Italy	1.8	70.2
15	Turkey	1.6	71.0	Turkey	1.6	72.1	Turkey	1.7	71.9
16	Bermuda	1.6	72.5	Bermuda	1.5	73.6	Bermuda	1.6	73.5
17	Russia	1.5	74.1	Russia	1.4	75.0	Russia	1.5	74.9
18	Indonesia	1.5	75.6	Indonesia	1.4	76.4	France	1.4	76.4
19	Liberia	1.2	76.8	France	1.3	77.8	Liberia	1.3	77.6
20	France	1.2	78.0	United Arab Emirates	1.2	78.9	Marshall Islands	1.2	78.8
21	Marshall Islands	1.2	79.2	Liberia	1.1	80.1	Indonesia	1.2	80.0
22	United Arab Emirates	1.1	80.3	Marshall Islands	1.1	81.2	Malaysia	1.1	81.1
23	Malaysia	1.1	81.4	Netherlands	1.1	82.3	United Arab Emirates	1.1	82.2
24	India	1.0	82.4	Malaysia	1.1	83.3	Cyprus	1.1	83.3
25	Netherlands	1.0	83.5	Cyprus	1.0	84.3	Netherlands	1.1	84.3
26	Cyprus	1.0	84.5	India	1.0	85.3	Canada	0.9	85.3
27	Canada	0.9	85.4	Canada	0.9	86.2	India	0.9	86.2
28	Bahamas	0.7	86.1	Iran	0.8	87.0	Bahamas	0.8	87.1
29	Sweden	0.7	86.8	Bahamas	0.8	87.7	Iran	0.8	87.9
30	Vietnam	0.7	87.5	Sweden	0.7	88.4	Vietnam	0.7	88.6
31	Thailand	0.7	88.2	Vietnam	0.7	89.0	Belgium	0.7	89.2
32	Iran	0.6	88.9	Thailand	0.7	89.7	Thailand	0.6	89.8
33	Spain	0.6	89.5	Belgium	0.6	90.2	Sweden	0.5	90.4
34	Belgium	0.6	90.0	Spain	0.5	90.8	Saudi Arabia	0.5	90.9
35	Philippines	0.5	90.5	Saudi Arabia	0.5	91.3	Israel	0.4	91.3
36	Saudi Arabia	0.5	91.0	Philippines	0.4	91.7	Spain	0.4	91.7
37	Israel	0.4	91.4	Israel	0.4	92.1	Switzerland	0.4	92.1
38	Ukraine	0.3	91.8	Switzerland	0.3	92.4	Philippines	0.3	92.4
39	Finland	0.3	92.1	Ukraine	0.3	92.7	Nigeria	0.3	92.7
40	Croatia	0.3	92.4	Croatia	0.3	93.0	Ukraine	0.3	93.0

Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Table 3B. Top 40 countries of ownership in mean CO_2 emissions (activity adjusted) - Fleets of more than 50 vessels

Rank	2007			2008			2009		
	Flag of registry	% of emissions	cumul	Flag of registry	% of emissions	cumul	Flag of registry	% of emissions	cumul
1	Israel	2.0	2.0	Israel	2.1	2.1	Israel	2.5	2.5
2	Bermuda	1.7	3.7	France	1.9	4.0	France	2.0	4.5
3	France	1.7	5.3	Bermuda	1.7	5.6	Bermuda	1.8	6.3
4	Taiwan	1.5	6.9	Denmark	1.6	7.3	Taiwan	1.6	7.9
5	Denmark	1.5	8.4	Taiwan	1.6	8.9	Denmark	1.5	9.4
6	Saudi Arabia	1.4	9.8	Germany	1.5	10.3	Saudi Arabia	1.4	10.8
7	Germany	1.4	11.2	Saudi Arabia	1.4	11.8	Germany	1.4	12.3
8	Kuwait	1.4	12.6	Kuwait	1.4	13.2	Kuwait	1.4	13.7
9	Panama	1.2	13.8	Panama	1.3	14.5	Panama	1.4	15.0
10	Greece	1.2	15.0	Greece	1.2	15.7	Greece	1.3	16.3
11	United Kingdom	1.1	16.1	Bahamas	1.1	16.8	Bahamas	1.3	17.6
12	Canada	1.1	17.2	United Kingdom	1.1	17.9	Belgium	1.2	18.8
13	Bahamas	1.1	18.3	Canada	1.1	19.0	United Kingdom	1.2	20.0
14	Belgium	1.0	19.3	Iran	1.1	20.1	Iran	1.2	21.2
15	United States of America	1.0	20.3	Belgium	1.0	21.1	Canada	1.2	22.4
16	Cyprus	1.0	21.4	United States of America	1.0	22.1	Monaco	1.2	23.6
17	Monaco	1.0	22.4	Cyprus	1.0	23.2	Liberia	1.1	24.7
18	Marshall Islands	1.0	23.4	Monaco	1.0	24.2	Marshall Islands	1.1	25.8
19	Liberia	1.0	24.4	Marshall Islands	1.0	25.2	Hong Kong	1.1	26.9
20	Hong Kong	1.0	25.3	Liberia	1.0	26.1	United States of America	1.0	27.9
21	Iran	1.0	26.3	Hong Kong	1.0	27.1	Malaysia	1.0	29.0
22	Malaysia	0.9	27.2	Malaysia	0.9	28.0	Cyprus	1.0	30.0
23	Spain	0.9	28.1	Switzerland	0.9	28.9	Japan	1.0	31.0
24	Singapore	0.9	29.0	Singapore	0.9	29.9	Switzerland	0.9	31.9
25	Venezuela	0.9	29.9	Japan	0.9	30.8	Singapore	0.9	32.8
26	Japan	0.9	30.8	Venezuela	0.8	31.6	United Arab Emirates	0.9	33.7
27	Italy	0.8	31.6	Spain	0.8	32.4	Korea (South)	0.9	34.5
28	Switzerland	0.8	32.5	Italy	0.8	33.3	Venezuela	0.8	35.4
29	Sweden	0.8	33.2	United Arab Emirates	0.8	34.1	China	0.8	36.2
30	United Arab Emirates	0.7	34.0	Korea (South)	0.8	34.9	Italy	0.8	37.0
31	Croatia	0.7	34.7	Sweden	0.8	35.6	Nigeria	0.7	37.7
32	Korea (South)	0.7	35.4	China	0.7	36.3	Spain	0.7	38.5
33	China	0.7	36.2	Croatia	0.7	37.1	Croatia	0.7	39.2
34	Brazil	0.7	36.9	Brazil	0.7	37.7	Sweden	0.7	39.9
35	Finland	0.7	37.6	Australia	0.7	38.4	Norway	0.7	40.5
36	Australia	0.7	38.2	Norway	0.7	39.1	Brazil	0.7	41.2
37	Norway	0.7	38.9	Finland	0.7	39.7	Australia	0.7	41.8
38	Mexico	0.6	39.6	Mexico	0.6	40.3	Poland	0.6	42.5
39	Nigeria	0.6	40.2	Nigeria	0.6	41.0	India	0.6	43.1
40	Chile	0.6	40.8	India	0.6	41.5	Mexico	0.6	43.6

Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Table 4A. Top 40 of total CO_2 emissions (activity adjusted), by flag of registry – Fleets of more than 50 vessels

Rank	2007			2008			2009		
	Flag of Registry	%of emissions	cumul	Flag of Registry	%of emissions	cumul	Flag of Registry	%of emissions	cumul
1	Panama	19.9	19.9	Panama	20.2	20.2	Panama	20.3	20.3
2	Liberia	10.4	30.4	Liberia	10.8	31.1	Liberia	10.9	31.2
3	China	4.2	34.6	Singapore	4.5	35.6	Marshall Islands	5.0	36.3
4	Bahamas	4.1	38.7	Marshall Islands	4.3	39.9	Hong Kong	4.8	41.1
5	Marshall Islands	4.1	42.8	Hong Kong	4.2	44.1	Singapore	4.6	45.6
6	Singapore	4.1	46.9	Bahamas	4.2	48.3	Bahamas	4.4	50.1
7	Hong Kong	4.0	50.9	China	4.0	52.3	China	4.1	54.2
8	Greece	3.6	54.5	Malta	3.4	55.7	Malta	3.7	57.9
9	Malta	3.5	58.0	Greece	3.4	59.1	Greece	3.5	61.5
10	Germany	3.0	61.0	Germany	3.2	62.3	Germany	2.9	64.4
11	Cyprus	2.3	63.3	United Kingdom	2.5	64.8	Cyprus	2.6	67.0
12	United Kingdom	2.3	65.6	Cyprus	2.4	67.2	United Kingdom	2.4	69.4
13	Japan	2.1	67.7	Japan	2.1	69.3	Antigua	2.0	71.4
14	Italy	1.9	69.6	Antigua	2.0	71.3	Japan	1.9	73.4
15	Antigua	1.8	71.4	Italy	1.8	73.2	Italy	1.7	75.0
16	United States of America	1.7	73.1	United States of America	1.6	74.7	Korea (South)	1.6	76.6
17	Korea (South)	1.7	74.8	Korea (South)	1.6	76.3	United States of America	1.3	77.9
18	Indonesia	1.3	76.1	Danish International Register	1.4	77.7	Norwegian International Register	1.2	79.1
19	Norwegian International Register	1.3	77.4	Norwegian International Register	1.3	79.0	Danish International Register	1.2	80.4
20	Danish International Register	1.3	78.7	Indonesia	1.2	80.1	Bermuda	1.1	81.5
21	Bermuda	1.1	79.8	Bermuda	1.1	81.2	Malaysia	1.0	82.5
22	Malaysia	1.0	80.8	Netherlands	1.0	82.2	Indonesia	1.0	83.5
23	Netherlands	0.9	81.7	Malaysia	0.9	83.2	Netherlands	1.0	84.4
24	Turkey	0.9	82.6	Turkey	0.9	84.0	Turkey	0.9	85.4
25	India	0.9	83.5	India	0.8	84.9	Isle of Man	0.8	86.2
26	Philippines	0.8	84.3	Isle of Man	0.8	85.7	India	0.8	87.0
27	Isle of Man	0.8	85.1	Philippines	0.7	86.4	Philippines	0.6	87.6
28	Russia	0.8	85.9	Russia	0.7	87.1	Russia	0.6	88.3
29	St Vincent	0.8	86.6	St Vincent	0.6	87.8	Vietnam	0.6	88.9
30	Thailand	0.6	87.3	France (FIS)	0.6	88.4	France (FIS)	0.6	89.4
31	France (FIS)	0.6	87.9	Thailand	0.6	88.9	St Vincent	0.6	90.0
32	Vietnam	0.5	88.4	Vietnam	0.5	89.4	Thailand	0.5	90.5
33	Cambodia	0.5	88.9	Cambodia	0.4	89.9	Belgium	0.4	90.9
34	Sweden	0.5	89.4	Sweden	0.4	90.3	Cambodia	0.4	91.2
35	Norway	0.5	89.8	Norway	0.4	90.7	Norway	0.3	91.6
36	Canada	0.4	90.2	Canada	0.3	91.0	Sweden	0.3	91.9
37	Taiwan	0.3	90.5	Belgium	0.3	91.4	Gibraltar	0.3	92.2
38	Brazil	0.3	90.8	Taiwan	0.3	91.7	Cayman Islands	0.3	92.5
39	Belgium	0.3	91.1	Brazil	0.3	92.0	Canada	0.3	92.8
40	Cayman Islands	0.3	91.4	Cayman Islands	0.3	92.2	Taiwan	0.3	93.0

Source: Author's calculation from IMO (2009) and LRF database (May 2009)

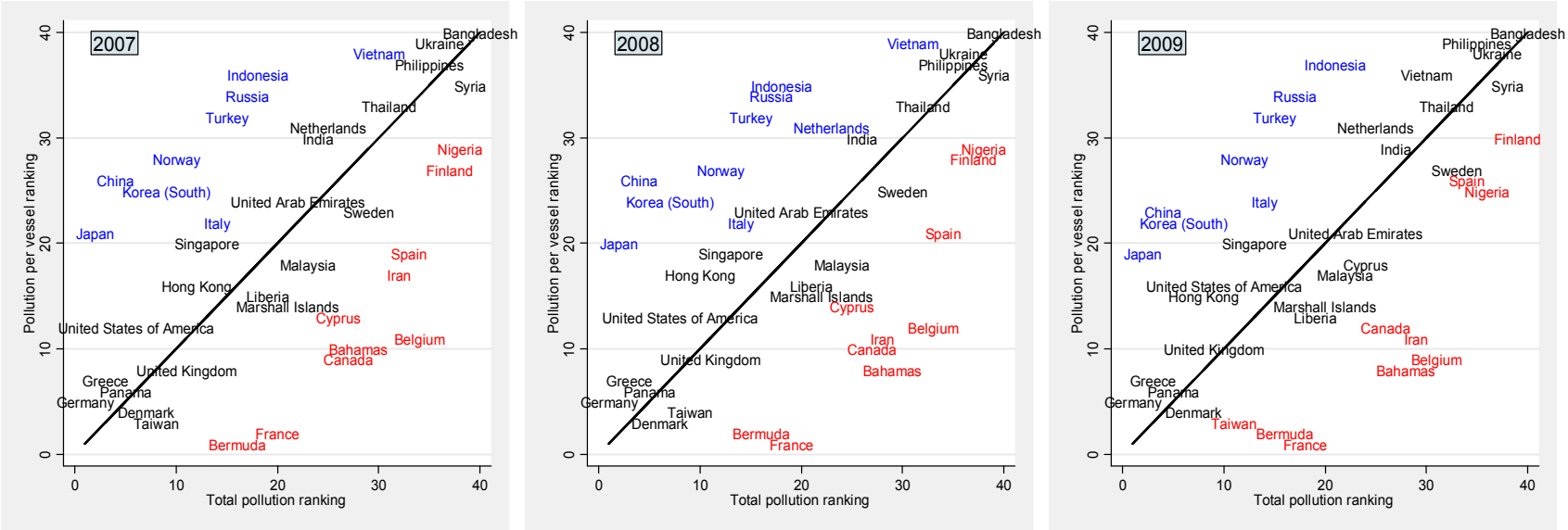
Table 4B. Top 40 of CO_2 emissions per vessel (activity adjusted), by flag of registry - Fleets of more than 50 vessels

Rank	2007			2008			2009		
	Flag of registry	%of emissions	cumul	Flag of registry	%of emissions	cumul	Flag of registry	%of emissions	cumul
1	Bermuda	2.8	2.8	Bermuda	2.9	2.9	Bermuda	3.3	3.3
2	France (FIS)	2.4	5.2	France (FIS)	2.4	5.3	France (FIS)	2.4	5.7
3	Germany	2.2	7.3	Germany	2.4	7.7	Germany	2.2	7.9
4	Liberia	1.8	9.1	Liberia	1.8	9.5	Liberia	1.8	9.7
5	Danish International Register	1.5	10.6	Danish International Register	1.6	11.1	United Kingdom	1.6	11.3
6	United Kingdom	1.5	12.1	United Kingdom	1.6	12.7	Belgium	1.5	12.8
7	Marshall Islands	1.4	13.5	Marshall Islands	1.4	14.2	Marshall Islands	1.5	14.4
8	Bahamas	1.3	14.9	Bahamas	1.4	15.5	Danish International Register	1.5	15.9
9	Hong Kong	1.3	16.2	Hong Kong	1.3	16.8	Bahamas	1.5	17.4
10	Singapore	1.2	17.4	Singapore	1.2	18.1	Hong Kong	1.4	18.8
11	Belgium	1.2	18.6	Belgium	1.2	19.3	Singapore	1.3	20.1
12	Greece	1.2	19.8	United States of America	1.2	20.5	Greece	1.2	21.3
13	United States of America	1.2	20.9	Greece	1.2	21.7	Panama	1.2	22.5
14	Panama	1.1	22.0	Panama	1.1	22.8	Isle of Man	1.2	23.6
15	Isle of Man	1.1	23.1	Isle of Man	1.1	23.9	Cyprus	1.1	24.8
16	Cyprus	1.1	24.2	Cyprus	1.1	25.0	United States of America	1.1	25.8
17	Norwegian International Register	1.0	25.2	Norwegian International Register	1.0	26.0	Norwegian International Register	1.1	26.9
18	Cayman Islands	1.0	26.2	Cayman Islands	1.0	27.0	Cayman Islands	1.0	27.9
19	Italy	1.0	27.2	Italy	1.0	28.0	Vanuatu	1.0	29.0
20	Vanuatu	0.9	28.1	Saudi Arabia	0.9	28.9	France	1.0	30.0
21	Malta	0.9	29.0	Vanuatu	0.9	29.8	Malta	1.0	30.9
22	Saudi Arabia	0.9	29.9	Malta	0.9	30.7	Malaysia	0.9	31.9
23	Sweden	0.8	30.7	Malaysia	0.8	31.5	Italy	0.9	32.8
24	Malaysia	0.8	31.5	Sweden	0.8	32.3	Taiwan	0.8	33.6
25	Taiwan	0.8	32.4	Taiwan	0.8	33.2	Saudi Arabia	0.8	34.4
26	Denmark	0.8	33.1	Australia	0.7	33.9	Australia	0.8	35.2
27	Spain	0.8	33.9	Brazil	0.7	34.6	Denmark	0.8	36.0
28	Australia	0.8	34.7	Denmark	0.7	35.3	China	0.7	36.7
29	Brazil	0.7	35.4	Spain	0.7	36.0	Brazil	0.7	37.3
30	France	0.7	36.1	United Arab Emirates	0.7	36.7	Sweden	0.7	38.0
31	Mexico	0.7	36.8	Croatia	0.7	37.3	Antigua	0.7	38.7
32	Croatia	0.7	37.5	France	0.7	38.0	Croatia	0.6	39.3
33	Venezuela	0.7	38.2	Mexico	0.7	38.6	Dominica	0.6	39.9
34	Canada	0.6	38.8	Antigua	0.7	39.3	United Arab Emirates	0.6	40.5
35	China	0.6	39.4	Venezuela	0.6	39.9	Korea (South)	0.6	41.1
36	Tuvalu	0.6	40.1	China	0.6	40.6	Canada	0.6	41.7
37	Dominica	0.6	40.7	Canada	0.6	41.2	Venezuela	0.6	42.3
38	Antigua	0.6	41.3	Tuvalu	0.6	41.8	Mexico	0.6	42.9
39	Madeira (MAR)	0.6	41.9	Dominica	0.6	42.4	Spain	0.6	43.5
40	Argentina	0.6	42.5	Netherlands	0.6	42.9	India	0.6	44.0

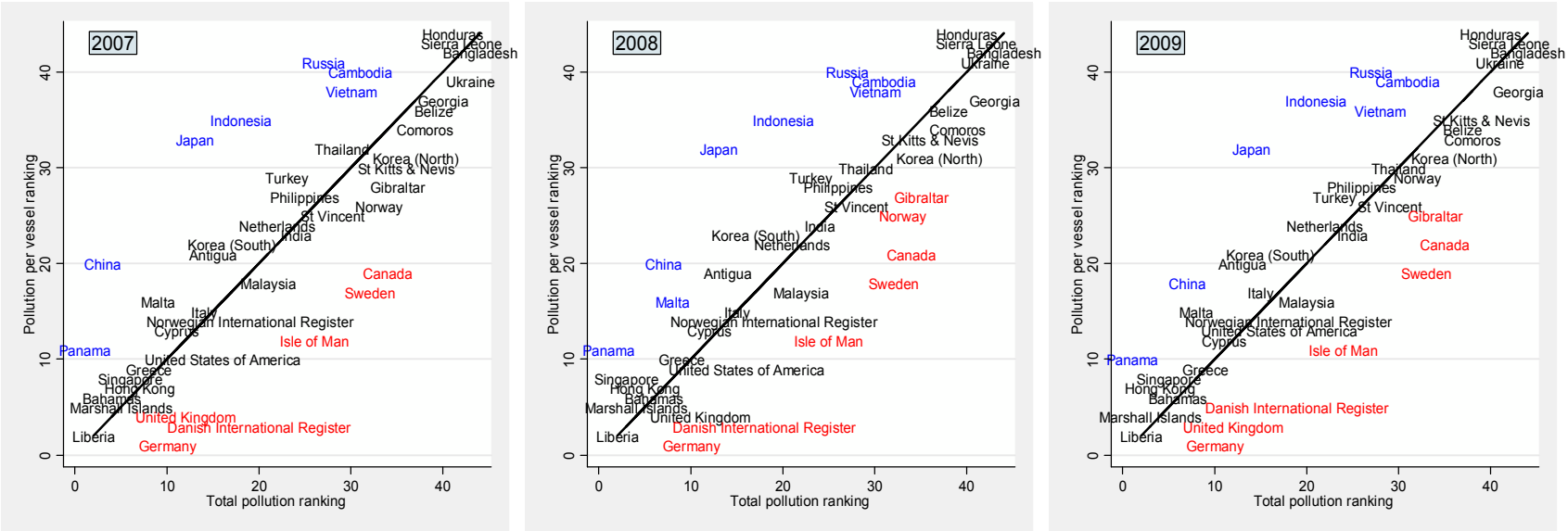
Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Figure 3. Total and mean CO_2 emissions ranking (activity adjusted) - Fleets of more than 150 vessels

A. By country of ownership



B. By flag of registry



Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Table 5 . Decomposition of CO_2 emissions in million tons by country in 2009

Country	Total pollution		Owned pollution		Exported pollution				Imported pollution				Net pollution	
	CO2 volume	rank	CO2 volume	Rank	CO2 volume	Rank	%	rank	CO2 volume	Rank	%	rank	CO2 volume	rank
Germany	136.06	1	30.30	2	105.75	2	77.73	11	0.59	21	0.43	36	-74.86	39
Japan	127.06	2	19.99	5	107.07	1	84.27	7	0.18	30	0.14	38	-86.90	40
Greece	84.53	3	28.70	3	55.83	3	66.04	17	7.58	10	8.97	19	-19.54	36
China	74.82	4	40.75	1	34.07	4	45.54	26	0.46	23	0.62	35	7.14	11
Panama	41.62	5	28.13	4	13.49	12	32.41	31	171.93	1	413.12	3	186.56	1
Denmark	32.11	6	1.04	36	31.07	5	96.75	2	0.52	22	1.63	28	-29.50	38
Korea (South)	31.02	7	15.25	9	15.77	10	50.84	24	0.29	26	0.93	31	-0.23	22
United States of America	29.23	8	9.21	13	20.01	8	68.47	16	5.45	12	18.64	14	-5.35	32
Hong Kong	28.98	9	17.88	6	11.10	14	38.31	29	29.27	6	101.00	7	36.05	6
United Kingdom	27.40	10	9.35	12	18.06	9	65.89	18	16.04	8	58.53	10	7.33	10
Norway	26.83	11	4.18	23	22.65	7	84.44	6	5.92	11	22.08	12	-12.55	35
Taiwan	26.45	12	2.70	28	23.75	6	89.79	3	0.10	35	0.38	37	-20.95	37
Singapore	24.86	13	15.55	7	9.31	17	37.45	30	30.49	5	122.68	6	36.73	5
Italy	20.68	14	15.33	8	5.35	23	25.89	33	4.08	14	19.71	13	14.05	8
Turkey	18.58	15	10.05	11	8.53	19	45.92	25	0.17	31	0.91	32	1.69	18
Bermuda	15.41	16	0.36	40	15.05	11	97.67	1	9.66	9	62.66	9	-5.04	31
France	15.27	17	2.13	31	13.14	13	86.05	5	2.72	16	17.79	15	-8.29	33
Russia	15.12	18	6.17	18	8.94	18	59.16	19	0.78	20	5.14	21	-1.99	26
Indonesia	13.12	19	10.84	10	2.28	32	17.39	37	0.42	25	3.21	23	8.98	9
Liberia	12.32	20	2.26	29	10.06	15	81.64	9	108.18	2	878.15	1	100.38	2
Netherlands	11.60	21	6.85	16	4.76	25	41.00	28	4.47	13	38.53	11	6.56	15
Marshall Islands	11.34	22	4.70	22	6.64	21	58.52	21	43.56	3	384.18	4	41.63	3
Cyprus	11.17	23	6.24	17	4.93	24	44.17	27	19.76	7	176.87	5	21.06	7
United Arab Emirates	11.16	24	1.18	33	9.97	16	89.41	4	0.12	34	1.04	30	-8.68	34
Malaysia	10.30	25	8.22	14	2.09	33	20.25	35	0.80	19	7.73	20	6.93	13
Canada	9.87	26	3.08	26	6.79	20	68.82	15	0.27	28	2.75	25	-3.44	29
India	9.28	27	8.03	15	1.25	37	13.44	40	0.23	29	2.46	26	7.01	12
Iran	8.32	28	1.94	32	6.38	22	76.65	12	0.01	39	0.11	39	-4.43	30
Bahamas	7.51	29	5.86	19	1.64	35	21.90	34	36.98	4	492.62	2	41.20	4
Vietnam	7.34	30	5.85	20	1.48	36	20.19	36	0.05	36	0.73	34	4.43	16
Sweden	6.72	31	2.94	27	3.78	28	56.30	22	1.19	17	17.73	16	0.34	20
Belgium	6.56	32	3.16	25	3.41	29	51.92	23	0.28	27	4.31	22	0.03	21
Thailand	6.11	33	5.11	21	1.00	38	16.43	38	0.14	32	2.22	27	4.24	17
Saudi Arabia	5.27	34	1.11	35	4.17	26	79.02	10	0.87	18	16.47	17	-2.19	27
Israel	4.64	35	0.85	39	3.79	27	81.71	8	0.13	33	2.84	24	-2.81	28
Philippines	4.25	36	3.60	24	0.65	40	15.21	39	3.61	15	84.97	8	6.57	14
Switzerland	3.60	37	0.92	38	2.68	30	74.52	13	0.00	40	0.00	40	-1.76	25
Spain	3.32	38	1.01	37	2.31	31	69.51	14	0.42	24	12.68	18	-0.88	24
Croatia	2.90	39	2.13	30	0.76	39	26.40	32	0.04	37	1.24	29	1.40	19
Ukraine	2.86	40	1.18	34	1.69	34	58.92	20	0.02	38	0.75	33	-0.49	23

Source: Author's calculation from IMO (2009) and LRF database (May 2009)

Appendix 1. Assumptions on representative activity-adjusted level by category of vessels (2008-2009)

Category	Sub-Category (all values in 1000)		2008/2007	2009/2008	Representative market
I. Tanker	1	200+ dwt	-3.34%	-3.18%	Total export volume in tons by VLCC vessels 2008/2007 and 2009 (first 6 months)/2008 (first 6 months)*
	2	120-200 dwt	-1.28%	-6.31%	Total exports volume in tons by Suezmax vessels 2008//2007 and 2009 (first 6 months)/2008 (first 6 months)*
	3	80-120 dwt	4.11%	0.46%	Total exports volume in tons by Aframax vessels 2008/2007 and 2009 (first 6 months)/2008 (first 6 months)*
	4	60-80 dwt	-0.99%	-0.28%	Total exports volume in tons by Panamax 2008/2007 and 2009 (first 6 months)/2008 (first 6 months)*
	5	10-60 dwt	-3.52%	-9.13%	Chartering volume in dwt 2008/2007 and 2009 (first 9 months average)/2008 average**
	6	0-10 dwt			
Product tanker	7	60+ dwt			
	8	20-60 dwt			
	9	10-20 dwt			
	10	5-10 dwt			
	11	0-5 dwt			
Chemical tanker	12	20 dwt+			
	13	10-20 dwt			
	14	5-10 dwt			
	15	0-5 dwt			
Other tanker	16	Other tankers			
LPG tanker	17	40+ dwt			
	18	0-40 dwt	9.43%	-10.20%	Total export volume in tons Middle East/North Sea 2008/2007 and 2009 (first 9 months)/average 2008*
LNG Tanker	19	92 dwt			
	20	0-92 dwt	6.22%	32.29%	Total number of sailings to Japan (in number of vessels) 2008/2007 and 2009 (average first 6 months) /average 2008*
Bulker	21	200+ dwt			
	22	100-200 dwt			
	23	60-100 dwt	-2.98%	17.19%	Total chartering volume in dwt 2008/2007 and 2009 (first 10 month average)/2008 average**
	24	35-60 dwt			
	25	10-35 dwt			
	26	0-10 dwt			
General cargo	27	10+ dwt			
	28	5-10+ dwt	-4.65%	-6.61%	Total number of sailings China (in dwt) 2008/2007 and 2009 (first 3 month average)/2008 average*
	29	0-5 dwt			
	30	Reefer	0.59%	-11.31%	Total number of sailings South America (in number of vessels) 2008/2007 and 2009 (first 3 month average)/2008 average*
Container	31	8+ teu			
	32	5-8 teu			
	33	3-5 teu	11.43%	-14.67%	Total number of sailings Asia (in number of vessels) 2008/2007 and 2009 (first 3 month average)/2008 average*
	34	2-3 teu			

	35 36	1-2 teu 0-1 teu			
Vehicule carriers	37 38	4+ cars 0-4 cars	4.81%	-14.36%	Total number of sailings (in number of vessels) Northern Europe 2008/2007 and 2009 (first 6 month average)/2008 average*
Roro	39 40	2+ lanes meters 0-2 lanes meters	-6.99%	-39.03%	Total number of sailings (in number of vessels) Roro Northern Continental Europe 2008/2007 and 2009 (first 3 months average)/2008 average*
Passenger/Roro **Ferry**	41 42 43 44	25+ speed 0-25 speed 25+ speed 0-25 speed			
Cruise	45 46 47 48 49	100+ gt 60-100 gt 10-60 gt 2-10 gt 0-2 gt	N/A	N/A	2008/2007 and 2009/2007 = 0

Source: authors from * Lloyd's Shipping Economist monthly and ** Drewry Shipping Monthly statistics