Marine Pollution Bulletin 60 (2010) 1455–1466

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

An empirical analysis of IOPCF oil spill cost data

Christos A. Kontovas *, Harilaos N. Psaraftis, Nikolaos P. Ventikos

Laboratory for Maritime Transport, National Technical University of Athens, Greece

ARTICLE INFO

Keywords:
Oil pollution
Oil spill cost
Environmental risk

ABSTRACT

This paper reports on recent analysis of oil spill cost data assembled by the International Oil Pollution Compensation Fund (IOPCF). Regression analyses of clean-up costs and total costs have been carried out, after taking care to convert to current prices and remove outliers. In the first place, the results of this analysis have been useful in the context of the ongoing discussion within the International Maritime Organization (IMO) on environmental risk evaluation criteria. Furthermore, these results can be useful in estimating the benefit of regulations that deal with the protection of marine environment and oil pollution prevention.

1. Introduction

The purpose of this paper is to report on recent regression analyses of oil spill cost data provided by the International Oil Pollution Compensation Fund (IOPCF). While it is generally accepted that the overall level of maritime safety has improved in recent years, further improvements are still desirable. The same is also true as regards the level of protection of the marine environment. In the last decade, the number of oil spills and the total quantity of oil spilled in the seas have declined. In spite of this positive development, one would like to know how the cost components associated with oil spills behave, and this paper attempts to shed some light into this question.

The aforementioned downward trend can be seen in Fig. 1, which is from the data provided by the International Tanker Owners Pollution Federation (ITOPF). ITOPF has maintained a database of more than 10,000 oil spills from tankers, combined carriers and barges and shows the number of spills per year of 7 tonnes or more for the period 1974–2008. It is apparent that there has been a quasi-steady decrease in the total number of spills. As one may also notice, most spills are small (7–700 tonnes). The same downward trend is apparent in the total annual quantity of oil spilled during the last decade. After the accidents of tankers 'Heaven' (144,000 tonnes) and 'ABT Summer' (260,000 tonnes) in 1991, no accident above 100,000 tonnes has happened and, thus, the total amount of oil spilled decreased continuously. Both downward trends can be shown to be statistically significant, as it can be checked by applying the Mann–Kendall test. This is in line with Burgherr (2007), who presents a global overview of accidental oil spills greater than 700 tonnes from all sources for the period 1970–2004, followed by a detailed examination of trends in accidental tanker spills.

Reduction of oil pollution is one of the stated goals of new regulations, including the implementation of double hulls for tanker vessels. The management of safety at sea is based on a set of accepted rules that are, in general, agreed upon through the International Maritime Organization (IMO) which is a United Nations Organization that deals with all aspects of maritime safety and the protection of the marine environment. Many of these regulations aim to reduce environmental risk and, more precisely, the risk that relates with accidental oil spillage. It can also be argued that much of the maritime safety policy worldwide has been developed in the aftermath of serious accidents (such as 'Exxon Valdez', 'Erika' and 'Prestige' in case of oil pollution). A big chapter that has only recently opened concerns environmental risk evaluation criteria. At the 55th session of Marine Environment Protection Committee (MEPC) that took place in 2006, the IMO decided to act on the subject of environmental criteria. At the 56th session of MEPC (July 2007) a correspondence group (CG), coordinated by the second author of this paper on behalf of Greece, was tasked to look into all related matters, with a view to establishing environmental risk evaluation criteria within Formal Safety Assessment (FSA). FSA is the major risk assessment tool that is being used for policy-making within the IMO. An issue of primary importance was found to be the relationship between spill volume and spill cost.

The analysis reported in this paper is an attempt to shed some light into this issue and describe recent regression analyses of oil spill cost data provided by the International Oil Pollution Compensation Fund (IOPCF). These analyses have been carried out by the authors and are in the same spirit as those carried out by Yamada (2009) (primarily) and Psarros et al. (2009) (secondarily) but differ from them on several points. We believe that these analyses and

* Corresponding author.
E-mail address: xkontovas@gmail.com (C.A. Kontovas).

0025-326X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2010.05.010

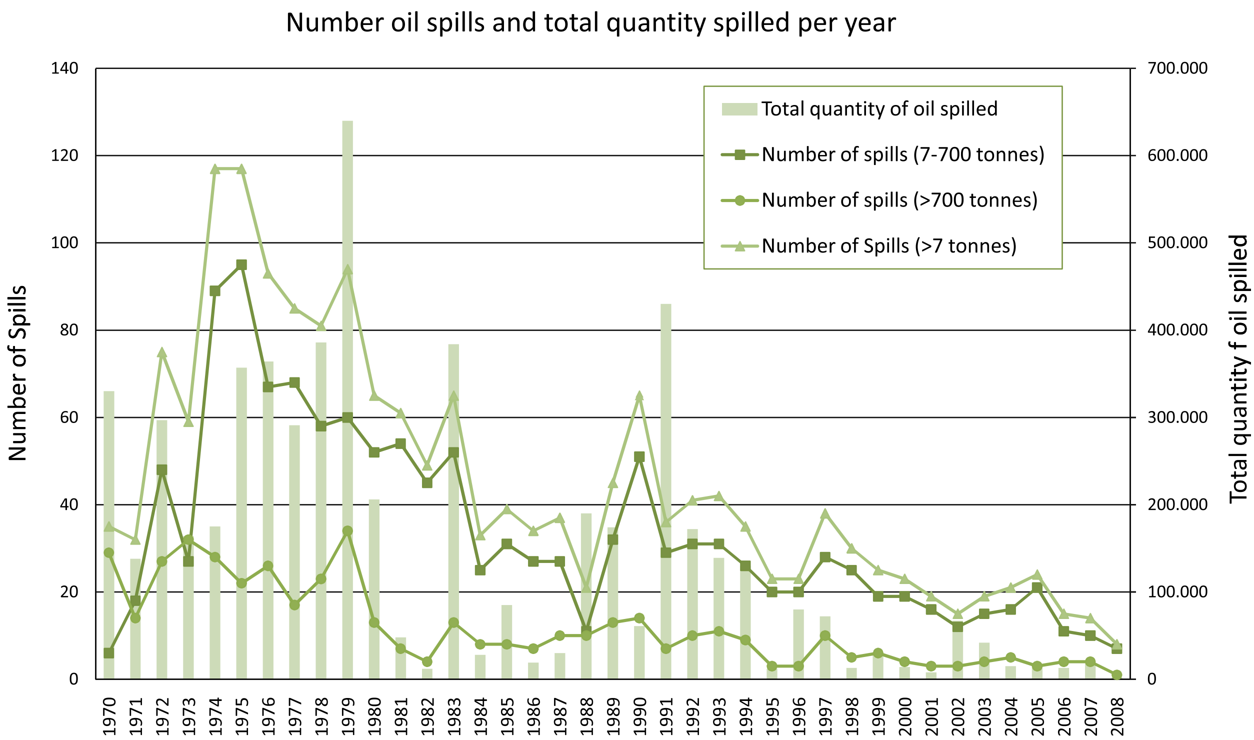

Fig. 1. Annual quantity of oil spilled and number of spills, 1974–2008. *Source:* ITOPF (2009).

their results can provide useful insights into the discussion on environmental risk evaluation criteria and in policy evaluation regarding the oil pollution of the marine environment by being able to estimate the damage cost of oil spills and, thus, the benefit from relative regulations in cost effectiveness and Cost-Benefit Analysis. In fact, these results have recently been adopted by the IMO/MEPC as a basis for further discussion on environmental risk evaluation criteria.

The rest of the paper is organized as follows. Section 2 presents a literature review on oil spill valuation, Section 3 reports on the data used and the methodology that was used in our analysis, Section 4 describes the results of the regressions and Section 5 talks about other studies using IOPCF data and compared the results. Finally, Section 6 reports on the possible uses of the analysis within FSA and Section 7 presents some recent developments and the conclusions.

2. Literature review

Even though the discussion at the IMO on environmental risk evaluation criteria for FSA has just started, the subject itself is not new, and substantial work has been performed over at least the last 30–35 years, mostly in the context of analyzing the economic impact of oil spills and contemplating measures to mitigate their damages. Among many other researchers, White and Molloy (2003) reported on the various components of the oil spill costs and on the significant difficulties in estimating these costs. Grigalunas et al. (1986) reported on the socioeconomic costs of the ‘Amoco Cadiz’ oil spill (1978, France). In the context of the ‘MIT oil spill model’, the second author of this paper and his colleagues at MIT used a ‘damage assessment model’ to estimate the damages of an oil spill in the context of optimizing oil spill response alternatives. They used damage cost estimates for various strategic spill response scenarios in the US New England region that ranged from about 29,000 USD/tonne (1983 dollars) for very small spills that typically occur close to shore to less than 300 USD/tonne for very large offshore spills (Psaraftis et al., 1986).

According to Liu and Wirtz (2006), five different categories of costs can generally be identified. We divide them into three groups: cleanup (removal, research and other costs), socioeconomic losses and environmental costs. By adding up these three cost categories we obtain the total cost of an oil spill. Beyond any doubt, the cost of an oil spill is a very difficult quantity to estimate. When spilled at sea, oil normally breaks up and is dissipated or scattered into the marine environment as a result of a number of processes that change the compounds of oil. There is also a general agreement (Etkin, 1999; Grey, 1999; White and Molloy, 2003) that the main factors influencing the cost of oil spills include the type of oil, location of the spill, amount of oil spilled and spillage rate, weather and sea conditions at the time of the spill.

The total cost of an oil spill can be derived by using at least four different methods (see Kontovas and Psaraftis, 2008). These are the following:

1. Adding up all relevant cost components (cleanup, socio-economic and environmental).
2. Estimating clean-up costs through modeling and then assuming a comparison ratio between environmental and socioeconomic costs.
3. Using a model that estimates the total cost such as the BOSCEM approach- of which more below.
4. Assuming that the total cost of an oil spill can be approximated by the compensation eventually paid to claimants. For example, compensation information is reported by the International Oil Pollution Compensation Fund (IOPCF) which publishes Annual Reports. This is the approach used in this paper.

One of the early studies on oil spill costs was performed by Cohen (1986). Based on the data owned by the USCG (regarding 95 accidents between 1973 and 1981) he proposed the use of a formula for the cost of the recovery of the oil spilled in relation to the volume spilled and the location of the oil spill. Later, Etkin (1999) devised a method for estimating clean-up costs (on per tonne of oil recovered basis) based on location, shoreline oiling, type of oil spilled, cleanup strategy and amount spilled. She further refined the model by adding two more variables: the specific type of location (allowing for three types of spills: offshore, coastal and port spills) and the country location. This new model by Etkin (2000) was based on a number of spills that happened worldwide while her previous models were based on US spills only. Her analysis (Etkin, 2001) showed that average costs could vary by at least one order of magnitude. Thus, the average clean-up cost (in 1999 USD per tonne) for an oil spill in Lithuania is 78.12, in Malaysia 76,589.29 and 25,614.63 in the United States. Etkin has also developed a credible method that can estimate the total costs of an oil spill which is known as the BOSCEM (Basic Oil Spill Cost Estimation Model). This was developed by Etkin for the US Environmental Protection Agency (EPA), and provides a methodology for estimating oil spill costs, including response costs and environmental and socioeconomic damages for actual or hypothetical spills. EPA BOSCEM was developed as a custom modification to a proprietary cost modeling program, ERC BOSCEM, created by extensive analyses of oil spill response, socioeconomic, and environmental damage cost data from historical oil spill case studies and oil spill trajectory and impact analyses (Etkin, 2004).

Shahriari and Frost (2008) have, very recently, developed a mathematical method to estimate clean-up costs based on regression analysis of 80 incidents during the period 1967–2002. The model parameters are spill quantity, oil density, distance to shore, cloudiness (used as a measure of how much sunlight reaches the oil which is the main factor that affects evaporation) and level of preparedness based on ITOPF estimations on how well different world regions cope with oil spills.

Finally, Liu et al. (2009) proposed a combination of simulating and estimating methods. They derive a formula to calculate the total cost in log linear relation to the spill size and have also tried to apply the methodology of stated choice experiments in order to derive the Willingness to Pay (WTP) among households to prevent coastal resources from polluting by oil spills. Note that relative techniques are mainly applied in estimating the environmental damage of oil spills. For a discussion on a range of approaches to estimate the economic value of non-market impacts in order to measure the environmental damages by indirectly link environmental resources to some market goods or even construct a hypothetical market in which people are asked to pay for these resources the reader is referred to Kontovas and Psaraftis (2008).

The work done in Ventikos et al. (2009) gives a clear picture of oil spill response cost in Greece. In this outline the aforementioned paper takes into account a number of variables to draft a model for the estimation of clean-up cost; namely type of oil, quantity of oil, and impact to shoreline. The results show that oil confrontation in Greece appears to be rather expensive, with a value of about 25,000 euro for the abatement of a spill of one ton of oil.

We now come to the fourth way to estimate the total cost of oil spills, which is by using compensation data and more specifically by using data from the compensations paid by the International Oil Pollution Compensation Fund (IOPCF). Among the first analyses was one that was performed by the IOPCF itself and presented in Grey (1999). Of compensation cases (68) were assessed mainly in order to test the limits of the compensation system. Four recent cases where IOPCF data were analyzed were known to the authors prior to their own analysis. It is not our purpose to comment on these in detail here. A more detailed comparison of the results will be presented in Section 5.

Friis-Hansen and Ditlevsen (2003) used the 1999 Annual Report (except those accidents that belonged to the categories "loading/unloading", "mishandling of cargo", and "unknown reason" which were removed from their analysis) and converted all amounts into Special Drawing Units (SDR) by an average annual exchange rate taken from the International Financial Yearbook. Then, historic national interest rates for Money Market Rates were applied to capitalize all costs into year 2000 units followed by a conversion into 2000 USD.

Hendricksx (2007) performed an analysis based on data of the 2003 Annual Report and analyzed 91 cases by converting each compensation amount into US Dollars using for each accident the exchange rate on December 31 of the year of occurrence. Exchange rates of the Bank of England were used for the currencies available and for the others an online website (OANDA.com) was used. There is no report that an inflation rate was used to bring these amounts into current Dollars**.**

Yamada (2009) performed a regression analysis of the amount spilled (W) and the total cost by using the exchange rates provided in the Annual Report itself. These rates can be used for conversion of one currency into another as of December 31, 2007 and do not take into account the time of the accident. Furthermore, no inflation rate was used to capitalize the costs into 2008 dollars. Note that spills less than 1 tonne were excluded by the analysis. His analysis formed the basis of Japan's submissions to the MEPC and, to a large extent, the basis of the MEPC decision to recommend a volume-based approach.

Last but not least, Psarros et al. (2009) used combined data from two datasets, namely the IOPCF report and the accident database developed by EU research project SAFECO II, and thus performed a regression analysis in 183 oil spill incidents. It is not immediately clear from their analysis what the SAFECO II database is and what (if any) biases it introduces to the analysis. The amounts were converted into 2008 US Dollars taking into account the inflation rate. We shall be commenting more on the last two papers later.

3. IOPCF data and methodology

Compensation for oil pollution caused by tankers is governed by four international conventions: the 1969 and the 1992 International Convention on Civil Liability for Oil Pollution Damage ("CLC 1969" and "CLC 1992") and the 1971 and 1992 conventions on the Establishment of an International fund for Compensation for Oil Pollution Damage ("1971 Fund" and "1992 Fund"). These conventions together create an international system where reasonable costs of cleanup and damages are met, first by the individual tanker owner up to the relevant CLC limit through a compulsory insurance and then by the international IOPCFs, if the amounts claimed exceed the CLC limits. More on compensation for oil pollution damage can be found in Jacobsson (2007), ITOPF(2010) and Liu et al. (2009). The IOPCF Annual Report (2008) presents the claims that the IOPCF dealt within the past. This report includes 107 accidents that are covered by the 1971 Fund and 33 by the 1992 Fund. For each accident the time and the place of accident are known and for most of the cases the volume of oil split and the costs claimed and eventually covered by the Fund are recorded. It should be noted that the IOPCF spill database does not include US spills, as the United States is not a signatory to the above conventions.[1]

Damages are grouped into the following categories:

- Cleanup
- Preventive measures
- Fishery-related
- Tourism-related

[1] The equivalent for the US is OPA's Oil Spill Liability Trust Fund (OSLTF). There is no single database on US oil spill costs, although the US Coast Guard maintains relevant data in at least two separate databases.

- Farming-related
- Other loss of income
- Other damage to property
- Environmental damage/studies

Table 1 presents an excerpt of the IOPCF (2008) Annual Report. Where claims are shown in the table as "settled" this means that the amounts have been agreed with the claimants, but not necessarily that the claims have been paid or paid in full. In our analysis we refer to clean-up cost as the cost that has been agreed (excluding cases where claims are pending) for clean-up of the damage and to total cost as the sum of all costs that are presented in the report. As one may notice, there are cases where clean-up cost is the only category that appears and, thus, the total cost is equal to the clean-up cost (see for example Table 1, cases 2 and 4).

Before describing our analysis, it is important to comment on the limitations of the IOPCF dataset. First of all, we should point out that the costs that IOPCF reports to the public are not 'real' oil spill costs. They only refer to the amount of money that was agreed to compensate the claimants. Although the IOPCF compensation figures are real and cannot be disputed, a question is if compensation figures can be taken to reasonably approximate real spill costs, or, failing that, if they can be used as realistic 'surrogates' of these costs.

Estimates of damages calculated by applying economic valuation methodologies claim for compensation and the compensation eventually paid to claimants can never be equal (Thébaud et al., 2005). Furthermore, IOPCF consists of three intergovernmental organizations (the 1971 Fund, the 1992 Fund and the Supplementary Fund) which provide compensation for oil pollution damage resulting from spills of persistent oil from tankers only. In addition, we further note that admissible claims cannot be paid in full, especially in the case of large spills, since the total compensation paid is limited by the 1992 Civil Liability Convention (CLC) and the 1992 Fund to a maximum of 203 million Special Drawing Units (SDR), this is approximately US$327 million (as at April 2008). For example, in the case of 'Prestige' totally 172 million Euros were paid from the 1992 Fund and CLC (IOPCF, 2009) which is only 2% of the total long-term oil spill costs (Liu and Wirtz, 2006). To be more accurate, limits depend on the gross tonnage of the ship – more information can be found in IOPCF (2009).

As said before, the United States is not part of the IOPCF, which as of November 2009 numbers 103 states. The same is true of China (not including Hong Kong). Therefore, spills like the 'Exxon Valdez' are not included in the analysis. Furthermore, as of November 2009, only 24 States are parts of the Supplementary Fund Protocol which increased the maximum payable compensation to approximately USD 1210 million (based on the conversion rate of the SDR to USD in April 2008).

Based on the latest IOPCF Annual Report the 1992 Fund contributions can be seen in Fig. 2. Interestingly enough, the most expensive claims (in total unit cost) come from Japan (see Table 2) which is the major contributor of the IOPCF and are small spills caused by mishandling of oil supply. Note that some of the spills given in Table 2 are removed from the final analysis as outliers and that in relevant studies such as the work of Friis-Hansen and Ditlevsen all spills caused by mishandling of oil supply were not taken into account.

Finally, another major issue raised by many researchers is that the IOPCF claims probably underestimate the cost of oil spills since they do not include environmental damage costs. Only admissible claims are taken into account to be compensated and, practically, according to historical data, fewer than 1% contained Natural Resource Damage assessments (Helton and Penn, 1999). Not to mention that, according to IOPCF, "*compensation for environmental damage* (*other than economic loss resulting from impairment of the environment*) *is restricted to costs for reasonable measures to reinstate the contaminated environment and, therefore, claims for damage to the ecosystem are not admissible*".

The seminal paper from Helton and Penn (1999) is among the best sources of costs related to Natural Resource Damage (NRD). NRD assessments are performed in the United States during the last decades and are the best source to estimate the environmental damage of the oil spills. The cost data concern 48 spill incidents across the US between 1984 and 1997 and according to the authors are skewed towards larger spills. Complete data are available for 30 cases and include oil spills from facilities and pipelines and even if this dataset cannot offer reliable results one of the main findings of Helton and Penn (1999) is that "*contrary to the public perception, costs for natural resource damages and assessment comprise only a small portion of total liability from an oil spill*". NRD costs in the original dataset vary from 2.3% ('Arco Anchorage') to 94.9% ('Apex Houston') of the total cost. It is worth to note that for the 'Nestucca' accident NRD cost was 20.5% and for the most expensive in terms of total cost case in the history of US that for 'Exxon Valdez' this figure comes down to 9.7%.

Taking into consideration all of the above, one might argue that IOPCF data does not represent a world-wide dataset, may not include all relevant costs and, by definition, there is an upper limit

Table 1
Excerpt of the IOPC 2008 Annual Report. Adopted from IOPCF (2008).

#	Ship	Date of incident	Place of incident	Flag state of ship	Gross tonnage (GRT)	Limit of ship owner's liability under 1969 CLC	Cause of incident[a]	Quantity of oil spilled (tones)	Compensation (amounts paid by 1971 Fund, unless indicated in contrast)
1	*Irving Whale*	7.9.70	Gulf of St Lawrence, Canada	Canada	2261	Unknown	Sinking	Unknown	–
2	*Antonio Gramsci*	27.2.79	Ventspils, USSR	USSR	27,694	Rbls 2431,584	Grounding	5500	Clean-up SKr95,707,157
3	*Miya Maru No8*	22.3.79	Bisan Seto, Japan	Japan	997	¥37,710,340	Collision	540	Clean-up ¥108,589,104 Fishery-related ¥31,521,478 Indemnification ¥9427,585
4	*Tarpenbek*	21.6.79	Selsey Bill, United Kingdom	Federal Republic Germany	999	£64,356	Collision	Unknown	Clean-up £363,550

[a] Note that the cause categories considered (Collision, Explosion/Fire, Grounding, Hull/Structural Failure and Other) are the same with those used by Lloyds' LMIU, LRFP and other casualty databases. Many such databases are more useful for aggregate statistical analysis of casualty data and less useful to draw conclusions as to the real cause of an accident and the sequence of events related to it. The latter may actually be a complex task to ascertain, as it may be the object of an accident investigation that may take years to complete, not to mention that it may be the outcome of a litigation process that can be equally as long. Another drawback of databases such as the above is that root cause information is usually missing; as such information can only be retrieved after considerable analysis of the accidents themselves. Working with casualty databases that have incomplete or even wrong cause information may skew the ensuing analysis, particularly regarding measures to reduce risk.

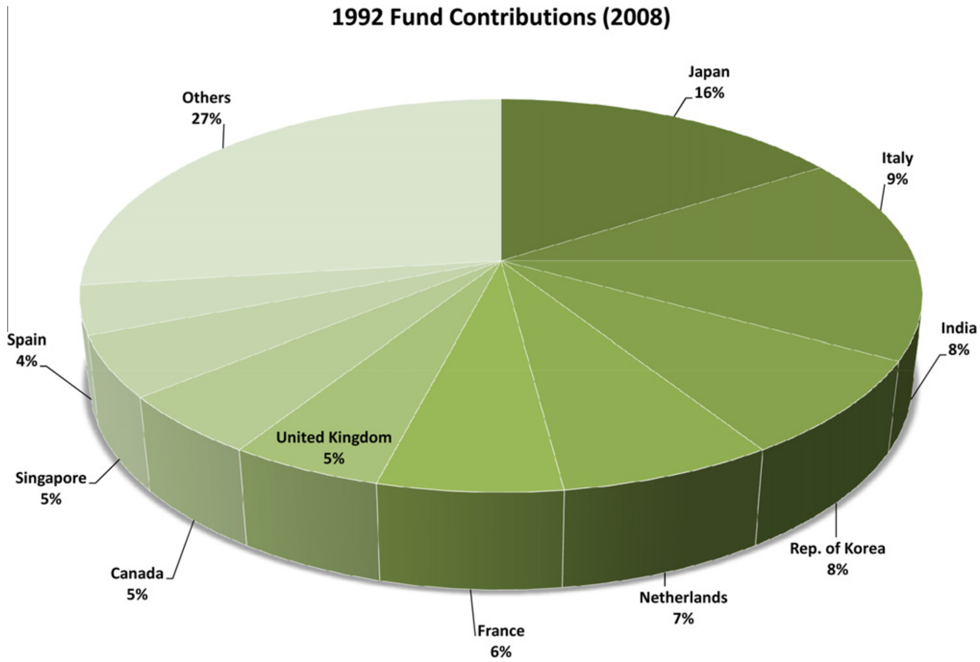

Fig. 2. 1992 Fund contributions 2008. *Source:* IOPCF (2009).

Table 2
List of the most expensive spills in terms of total per-tonne cost.

	Ship name	Year	Spill size (tn)	Place	Flag	Cause
1	Plate Princess	1997	3.2	Venezuela	Malta	Overflow during loading operation
2	Daiwa Maru No. 18	1997	1.0	Japan	Japan	Mishandling of oil supply
3	Shinryu Maru No. 8	1995	0.5	Japan	Japan	Mishandling of oil supply
4	Volgoneft 139	2007	1600.0	Strait of Kerch	Russia	Breaking
5	Dainichi Maru No. 5	1989	0.2	Japan	Japan	Mishandling of cargo
6	Kriti Sea	1996	30.0	Greece	Greece	Mishandling of supply
7	Tsubame Maru No. 31	1997	0.6	Japan	Japan	Overflow during loading operation
8	Shosei Maru	2006	60.0	Japan	Japan	Collision
9	Iliad	1993	200.0	Greece	Greece	Grounding
10	Sambo No. 11	1993	4.0	Korea	Korea	Grounding

to the maximum oil spill cost that can be reimbursed. Thus, the use of such data to estimate total oil spill costs may be questioned, even in the case of oil spills caused by tankers only. On the other hand, if there are any actual costs that are paid to victims of oil pollution, this is probably as good a source to document such costs as anyone. Plus, it is clear that this analysis can be amended with additional data, to the extent that such data become available.

In order to perform our analysis we followed the steps below:

1. We removed all incomplete entries and claims that were not eventually paid. For example, case 4 (see Table 1) provides no information on the quantity of oil spilled and thus has been excluded from the analysis although the amount of clean-up cost agreed is known.
2. All claims for the cleanup and the total cost categories (in the case of multiple claims) were added up by converting them to US Dollars at the time of the accident. We note that we are aware of the fact that the year of the accident and the year when the amount agreed was paid are not the same but this was the only available information. Furthermore, the exchange rates used in these conversions were found in various CIA Factbooks and in a list of foreign currency units per dollar that is compiled by Antweiler (2009).
3. The cost of the previous step was capitalized into 2009 US Dollars by using conversion factors based on the Consumer Price Index (CPI).

This way we arrived at two datasets, one having data on the clean-up cost (CC) and the volume (V) and another on the total cost (TC) and the volume (V). These datasets were not disjoint. In fact, the first dataset contained 84 entries, the second had 91 entries, and 68 spills reported both CC and TC.

According to Friis-Hansen and Ditlevsen (2003), the logarithm of the oil spill volume and the logarithm of the total spill cost are positively correlated, having a very high correlation coefficient. This was also observed by Hendricksx (2007), Yamada (2009) and Psarros et al. (2009). Our analysis of possible fits concluded that the double logarithmic, the multiplicative and the double reciprocal have the highest correlation coefficients and R-squared values. Therefore, costs (TC and CC) and volumes (V) were Log-transformed and a linear regression was performed for the two cases.

The necessary conditions for a linear regression to be valid were tested and an analysis of variance (ANOVA) was also performed. Furthermore identification of outliers was performed by carefully examining studentized residuals with an absolute value greater than 3. Note that a studentized residual is the quotient resulting from division of a residual by an estimate of its standard deviation. The regression analysis was repeated until no outliers could be found. Finally, the linear regression formulas in double logarithmic form were transformed into non-linear regression curves. The results of the regression analyses are presented in the following section.

4. Results of the regression analysis

4.1. Clean-up cost (CC)

After removing incomplete entries, a dataset of $N = 84$ spills for the period 1979–2006 was used for this regression analysis (see Fig. 3) and outliers were removed.

The minimum volume was 0.2 tonnes and the maximum was 84,000 tonnes. The average spill was 4055.82 tonnes with a standard deviation of 14,616.15 tonnes and the median was just 162.5 tonnes. Even without a histogram one could easily realize that most claims came from relatively small spills. There were only 10 spills above 5000 tonnes and, thus, one should be very careful when using the regression formulas to extrapolate the cost of large spills.

The equation of the fitted model using linear regression was

$$\text{LOG10(Cleanup Cost)} = 4.64773 + 0.643615\ \text{LOG10(V)}$$

or,

$$\text{Cleanup cost} = 44,435\ V^{0.644} \quad (1)$$

The R-squared statistic indicates that the model as fitted explains 61.5254% of the variability in LOG10(Clean-up Cost). The correlation coefficient (Pearson's correlation coefficient p) equals 0.7844, indicating a strong relationship between the variables. We also performed an analysis of variance (ANOVA) which indicated that there is a statistically significant relationship between LOG10(Clean-up Cost) and LOG10(V) at the 95.0% confidence level.

Furthermore, an average per tonne oil spill clean-up cost using the IOPCF database was calculated by dividing the total amount paid by the Fund for cleanup by the total amount of oil that was spilled. According to our analysis, this value came to **1639 USD (2009) per tonne.**

4.2. Total cost (TC)

Following the same methodology as in the previous step, a regression analysis of log(Total Cost) and log(Spill Size) was performed initially for $N = 91$ spills (for the period 1979–2006). The analysis of the studenized residuals revealed the existence of a total number of eight possible outliers. These outliers were removed. After three consecutive regressions we arrived at the final dataset of $N = 83$ spills (see Fig. 4).

The minimum volume here was 0.1 tonnes and the maximum was 84,000 tonnes. The average spill was 4854.29 tonnes, with a standard deviation of 16,064 tonnes and the median is just 140 tonnes. There are only 11 spills above 5000 tonnes.

The equation of the fitted model using linear regression was

$$\text{LOG10(Total Cost)} = 4.71123 + 0.727567\ \text{LOG10(V)}$$

or,

$$\text{Total cost} = 51,432\ V^{0.728} \quad (2)$$

The R-squared statistic indicated that the model as fitted explains 78.26% of the variability in LOG10(Clean-up Cost). The correlation coefficient (Pearson's correlation coefficient p) equals 0.8846, indicating a strong relationship between the variables.

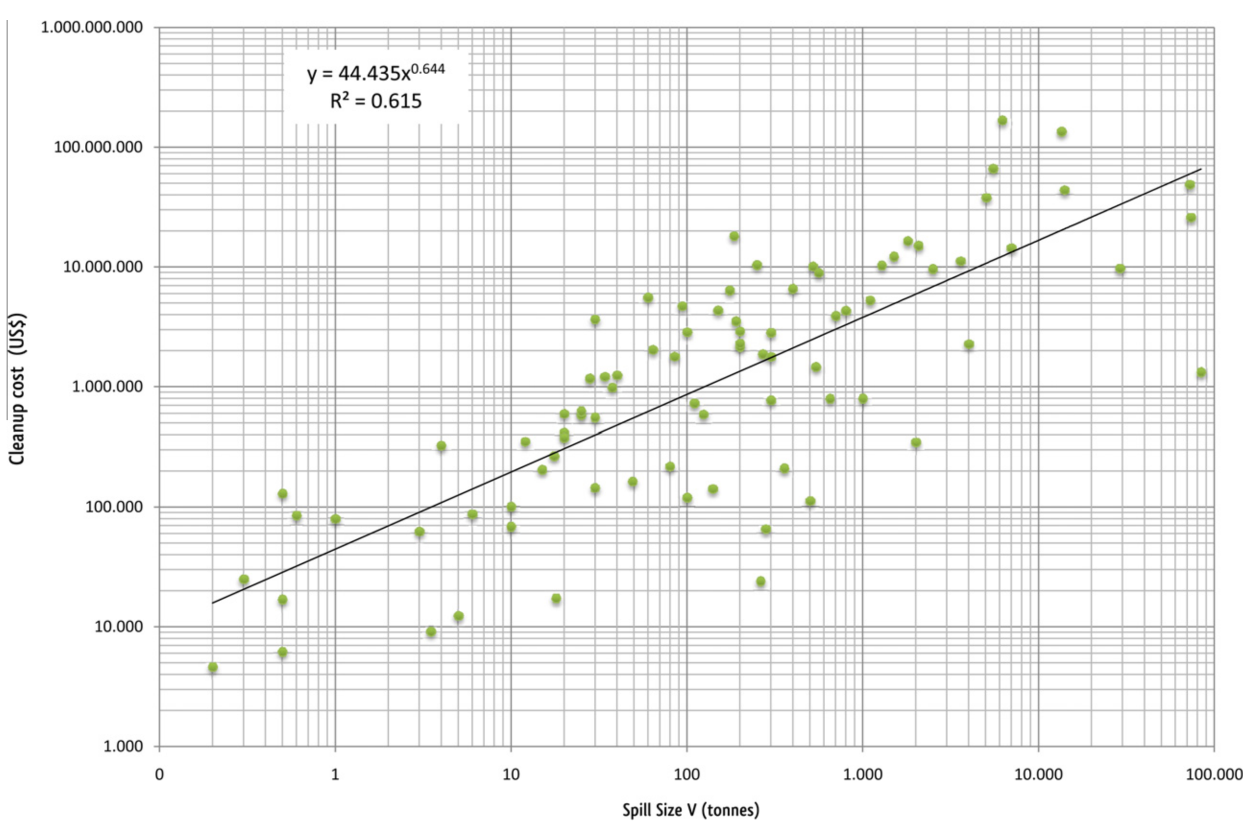

Fig. 3. Linear regression of Log(Spill Size) and Log(Clean-up Cost).

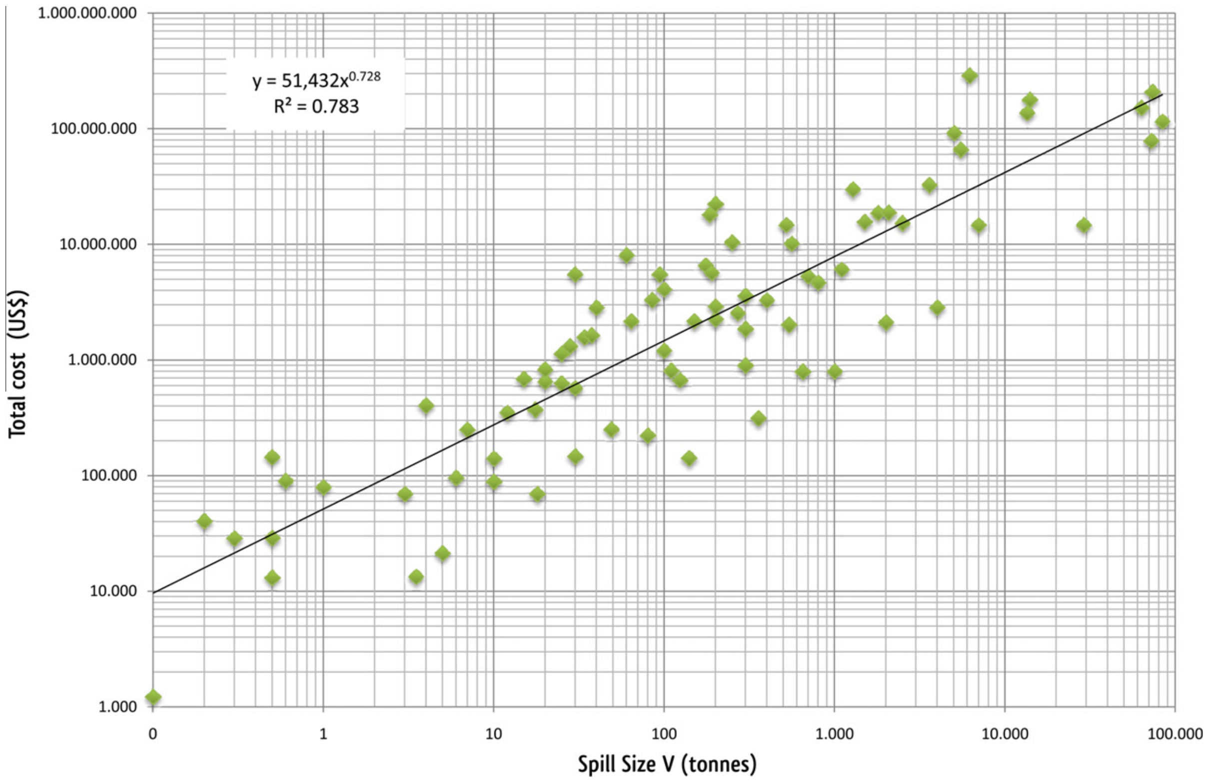

Fig. 4. Linear Regression of Log(Spill Size) and Log(Total Cost).

Again, the analysis of variance (ANOVA) indicates that there is a statistically significant relationship between LOG10(Total Cost) and LOG10(V) at the 95.0% confidence level.

As before, an average per tonne oil spill total cost using the IOPCF database was calculated by dividing the total amount paid by the Fund by the total amount of oil that was spilled. According to our analysis, this value comes to **4118 USD (2009) per tonne.**

It has to be noted that our regression analysis was very carefully performed in order to identify possible outliers, given the high sensitivity of the outcome on the dataset that we chose. **Outliers at both ends of the spectrum were removed**, that is, both for very low and for very high total spill costs per unit volume. In order to illustrate the sensitivity of including or not including such spills, we present the following for a hypothetical cost for one tonne spill. The total cost given by the regression formula for a hypothetical oil spill of 1 tonne is 51,437 USD. The results would have changed dramatically if some outliers had not been removed. For example, let us have a look at two extreme accidents both caused by mishandling of oil supply in Japan. The 'Kifuku Maru' accident in 1982 resulted in a spillage of 32 tonnes. The amount of money (converted into 2008 USD) that was paid for compensation was just 165 USD per tonne, a very low value. On the other hand, in 1997 the accident of 'Daiwa Maru No 18' resulted in one tonne spillage that costed more than 4.5 million USD. If the extremely high cost value of the 'Daiwa Maru No 18' had been included in the regression the formula would produce a total per-tonne cost for the hypothetical spill of one tonne of 56,058 USD. On the other hand, the extremely low, in terms of cost, case of 'Kifuku Maru' would have pushed the same value to as low as 46,706 USD.

4.3. Analysis of the total cost to clean-up cost ratio

Vanem et al. (2007a,b), taking into account the work of Jean-Hansen (2003), McCay et al. (2004) and Etkin (2004), concluded that a ratio of 1.5 should be assumed for the ratio of socioeconomic and environmental costs divided by clean-up costs. Thus, the total oil spill cost is 2.5 times the cost of cleanup, according to their analysis.

The data provided by the IOPCF Annual Report can be used to estimate an average total cost/clean-up cost ratio, for the sample of spills for which the values of both CC and TC are available. Since we are only interested in the ratio, there is no need to do the conversions discussed before (i.e. to use the exchange rate and the CPI index). Furthermore, accidents for which the claimed costs were only clean-up costs have to be removed. If clean-up cost is the only cost category available, this means that the total cost (as in the analysis performed above) would be equal to the total cost and in this case the ratio will be equal to 1. In order to remove this bias, all ratios equal to 1 have been removed, although this probably biases the analysis towards higher total cost to clean-up cost ratios. A ratio of 87,547 of the 'Braer' accident was also removed as an outlier. The dataset of the $N = 68$ ratios that were left (see Fig. 5) has a minimum ratio of 1.002, a maximum of 10.01, a mean of 1.929 and a median of 1.287. The median is the measure of center (location) of a list of numbers. Unlike the mean, the median is not influenced by a few very large values in the list and may be a more appropriate criterion for this purpose.

Based on the above figure, it seems that the factor of 2.5, taken by project SAFEDOR to represent the average ratio of total spill cost to clean-up cost globally, is probably on the high side.

5. Comparison with similar studies

5.1. Total costs

The following table summarizes the various oil spill total cost volume-based regression formulas and the corresponding R-squared values for this study, the study of Psarros et al. (2009)

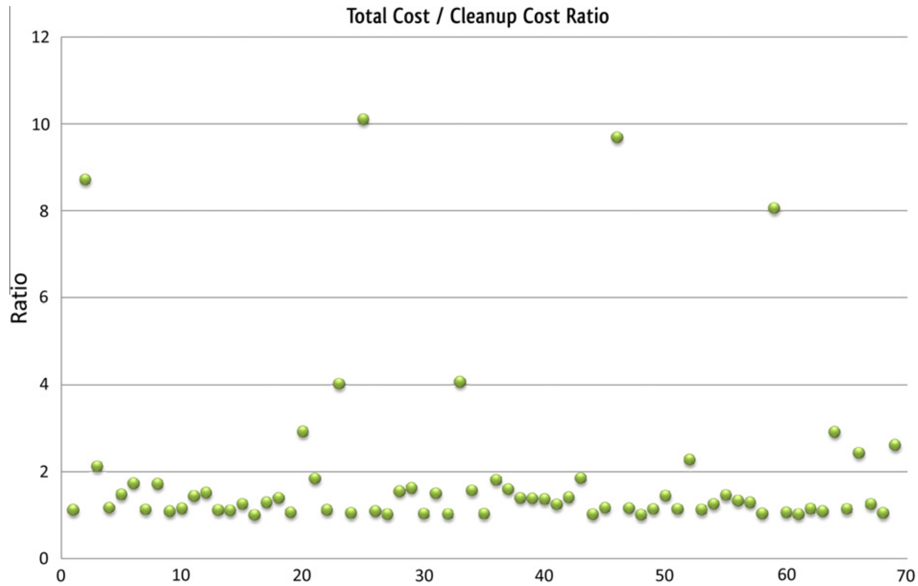

Fig. 5. Total cost/clean-up cost Ratio. *Source*: Data from IOPCF (2008).

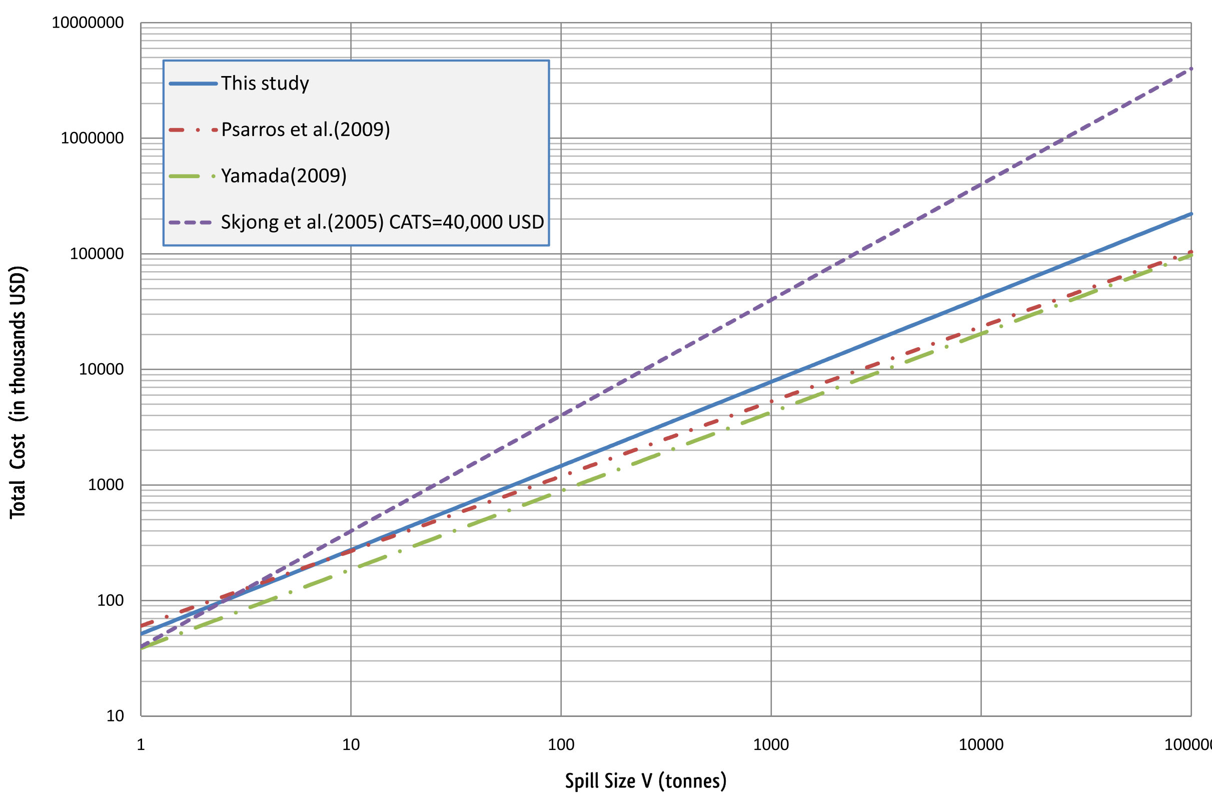

Fig. 6. Comparison of studies – total costs per tonne (in semi-log plot).

and the study of Yamada (2009). For comparison purposes, we also include the constant value of 40,000 USD/tonne for oil spill total cost as presented in Skjong et al. (2005) and Vanem et al. (2007a,b), when the authors proposed the cost effectiveness threshold value of 60,000 USD/tonne for CATS (for "Cost to Avert one Tonne of Spilled oil"). CATS is defined as the ratio of the expected cost of implementing a measure against oil pollution divided by the expected oil spill volume averted by it (more on this in Section 6).

For the four studies mentioned above, Fig. 6 displays the total unit cost (in log–log plot).

What is interesting in Table 3 is that our study produces a higher TC than Yamada's for all values of *V*, a higher TC than the one in Psarros et al. (2009) for all oil spill sizes more than about 10 tonnes, and a lower TC than in Skjong et al. (2005) for all *V* more than about 10 tonnes. Still, Psarros et al. (2009) derive a much higher average value, equal to about 54,000 USD/tonne, based on the average value of the ratio 'total cost/spill volume' for a log-normal distribution. Actually Psarros et al. (2009) went one step further: they multiplied the 54,000 figure with the $F = 1.5$ assurance factor and derived a 82,000 USD/tonne figure, which was then dropped in favor of the original constant 60,000 USD/figure. But, and for the reasons that we will outline in the next section, in this particular case we do not think that the 54,000 USD/tonne average ratio can be justifiably used in an environmental FSA.

What is equally interesting in the above table is the higher R-squared value of our study versus those of the others, implying a better fit with the data, and possibly a more reliable representation of spill costs on a volume basis. This is mainly explained by the removal of the outliers as mentioned earlier.

5.2. Unit and marginal costs

Lately, the relevant discussion at the IMO on this subject has concluded that a volume-dependent "costs of averting a tonne of oil spilled" captures the tendency of a per-tonne basis remedial cost of actual oil spill accidents. In that sense, the use of a function rather that a threshold is preferred.

By dividing regression formulas (1) and (2) by V one can obtain the **unit costs** as follows:Unit Clean-up Cost (UCC)

$$\text{UCC} = 44,435 \cdot V^{-0.356} \tag{3}$$

Unit Total Cost (UTC)

$$\text{UTC} = 51,432 \cdot V^{-0.272} \tag{4}$$

One can see that both unit costs are decreasing functions of V, as expected. Fig. 4 presents a comparison of the total per-tonne costs as given in relevant works.

Furthermore, when talking about a cost-effectiveness criterion one also talks about **marginal costs**. The idea of consideration of the marginal cost as described in the previous section was also presented in Yamada (2009) and supported by Japan (see doc. MEPC 58/17/1).

Given the above the marginal non-linear costs can be estimated by differentiating regression formulas (1) and (2) with respect to V as follows:Marginal Clean-up Cost (MCC)

$$\text{MCC} = \frac{d}{dV}\left(44,435 \cdot V^{0.644}\right) = 28,616 \cdot V^{-0.356} \tag{5}$$

Marginal Total Cost (MTC)

$$\text{MTC} = \frac{d}{dV}\left(51,432 \cdot V^{0.728}\right) = 37,442 \cdot V^{-0.272} \tag{6}$$

The marginal costs MCC and MTC are interpreted as the additional costs if one more tonne of oil is spilled. As expected, these are decreasing functions of V too. Marginal values are extremely important in policy evaluation. According to Goodman (2004), whereas using average cost we consider the total (or absolute) costs and outcomes of an intervention, marginal cost analysis considers how outcomes change with changes in costs (e.g., relative to a comparator), which "*may provide more information about how to use resources efficiently. Marginal cost analysis may reveal that, beyond a certain level of spending, the additional benefits are no longer worth the additional costs*". For more discussion on the use of marginal values see Section 6.

The following Table 4 shows values of these per-tonne costs for some representative values of V. V is in tonnes and the per-tonne values are in USD/tonne.

With bold italics we have indicated figures above the respective figures based on Skjong et al. (2005). If the 60,000 USD/tonne threshold is used for CATS, both UCC and MCC are 16,000 USD/tonne, and both UTC and MTC are 40,000 USD/tonne, irrespective of V. If a variable scale CATS is used, the above figures as well as the averages of 1639 and 4118 USD/tonne defined earlier could be of use. It is seen that our unit and Marginal Clean-Up Cost figures are below 16,000 USD/tonne for all but very small spills, and most are well below that. For our unit and marginal total cost figures, almost all are below 40,000 USD/tonne, and most are well below that.

The precise way such figures can be used is yet to be determined, and it is among the subjects of discussion at the IMO how the volume-based approach will be integrated within the FSA method. The general framework of Psaraftis (2008) might be useful in that regard, but other approaches may also be of interest.

Speaking of single-value thresholds based on ratios, one should be very careful with their use. Two statistics that one should be particularly careful with are (a) the average of the ratio 'clean-up cost/spill volume', and (b) the average of the ratio 'total cost/spill volume'. For our data, these average ratios are estimated at **23,085 USD/tonne** and **33,425 USD/tonne,** respectively.

It is perhaps tempting to use the above average ratios in an FSA study. But we think that caution should be exercised if anything like this is contemplated. If X and Y are two random variables, then

$$E(X/Y) = E(X)E(1/Y) + \text{Cov}(X, 1/Y)$$

where E is the expectation operator and Cov is the covariance operator.

Note that **only if X and Y are independent**, it is $E(X/Y) = E(X) E(1/Y)$. Furthermore, $E(1/Y)$ is **not equal** to $1/E(Y)$ in general.

This means that $E(X/Y)$ is not equal to $E(X)/E(Y)$ in general, even if X and Y are independent.

In our case, let X = CC (clean-up cost) and $Y = V$ (volume). Even if CC and V are independent (which they are clearly not), the average ratio of spill clean-up cost divided by spill volume **is not** necessarily equal to the ratio of the average spill clean-up cost divided by the average spill volume. This is precisely the reason why the average ratios of **23,085** and **33,425** USD/tonne reported above are different (in fact in our case significantly higher) than the respective averages of **1639** and **4118** USD/tonne computed earlier.

What this means is that **one should be careful not to mistake averages of ratios as ratios of averages,** as significant miscalculations may occur otherwise. In an FSA, the way such averages would be used could be in the event trees in the Risk Analysis step, where for each branch an average spill volume would have to be multiplied by an appropriate per-tonne spill cost. In that sense, it would be inappropriate to multiply $E(\text{CC}/V)$ by $E(V)$, as this could seriously miscalculate $E(\text{CC})$.

Table 3
Comparison of total cost formulas.

Study	Total cost = f (volume)	R^2
This study	Total cost = $51,432 \cdot V^{0.728}$	0.784
Psarros et al. (2009)	Total cost = $60,515 \cdot V^{0.647}$	0.507
Yamada (2009)	Total cost = $38,735 \cdot V^{0.66}$	0.460
Skjong et al. (2005)	Total cost = $40,000 \cdot V$	N/A

Table 4
Unit and marginal cost values.

V	UCC	UTC	MCC	MTC
1	***44,435***	***51,432***	***28,616***	37,442
10	***19,576***	*27,494*	*12,607*	19,957
100	*8624*	*14,697*	*5554*	10,644
1000	*3799*	*7857*	*2447*	5677
10,000	*1674*	*4200*	*1078*	3028
100,000	*737*	*2245*	*475*	1615

The right way to arrive at $E(\mathrm{CC})$ would be to multiply $\{E(\mathrm{CC})/E(V)\}$ with $E(V)$.

The same is true for TC versus V.

Similar considerations pertain to the possible use of medians as statistics. In our case, the median clean-up cost is **10,467 USD/tonne** and the median total cost is **14,082 USD/tonne**. A median has the advantage over the mean that it is not influenced by a single large or small value, so the possible use of such statistics in FSA should be explored. But caution should be exercised here as well so as to avoid possible pitfalls.

In this respect, a point has to be made on the \$54,390/tonne average spill cost per-tonne figure derived by the analysis of Psarros et al. (2009), which we understand to be the average of the ratio 'spill cost/spill volume' $E(C/V)$ for a log-normal distribution. Note that this corresponds to the 80-percentile of the distribution. What should rather be looked at is not the average of the ratio**, but the ratio of averages**, that is, total spill cost by total spill volume, which we speculate to be much lower. The \$54,390 figure is a $E(C/V)$ figure, and, as such, has no practical meaning.

It should be mentioned here that Psarros's analysis arrives at a **marginal cost** of \$9025/tonne. But the authors rather use the \$54,390 figure to arrive at a CATS threshold of more than \$80,000/tonne (by multiplying by 1.5).

6. Possible uses of the analysis within Formal Safety Assessment (FSA)

Formal Safety Assessment (FSA) was introduced by the International Maritime Organization (IMO) as "a rational and systematic process for accessing the risk related to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks" (see IMO, 2007). FSA aims at giving recommendations to relevant decision makers for safety improvements under the condition that the recommended measures (Risk Control Options) reduce risk to the "desired level" and are cost effective. FSA is, currently, the major risk assessment tool that is being used for policy-making within the IMO, however, until now its main focus was on assessing the safety of human life. No environmental considerations have been incorporated thus far into FSA guidelines. Also note that FSA exhibits some limitations and deficiencies. The reader is referred to Kontovas and Psaraftis (2006, 2008, 2009) and Giannakopoulos et al. (2007) for a discussion on these issues.

The fourth step of a Formal Safety Assessment is to perform a Cost-Benefit Analysis (CBA) so as to pick which RCOs are most cost effective. According to the FSA guidelines, one stage of this step is to "*estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option*".

In theory, the analytical tool of Cost Effectiveness Analysis is the **incremental cost-effectiveness ratio** (ICER), also called marginal cost-effectiveness ratio, given by the difference in costs between two actions divided by the difference in outcomes between these two, with the comparison typically being between an action that is proposed to be implemented and the current status.

In the scope of this paper, the following ICER indices can be formulated:

Gross Cost Effectiveness Index (GCEI)

$$\mathrm{GCEI} = \frac{\Delta C}{\Delta R} \tag{7}$$

Net Cost of Averting a Fatality (NCEI)

$$\mathrm{NCEI} = \frac{\Delta C - \Delta B}{\Delta R} \tag{8}$$

where ΔC is the cost per ship of the action (e.g., measure, Risk Control Option) under consideration (\$); ΔB is the economic benefit per ship resulting from the implementation (\$), and ΔR is the risk reduction per ship, in terms of the number of tonnes of oil averted.

Currently only one such index is being extensively used in FSA applications. This is the so-called "Cost of Averting a Fatality" (CAF) and is expressed in two forms: Gross and Net. These two indexes are the incremental cost-effectiveness ratios (in Gross and Net form) for risk reductions in terms of the number of fatalities averted. In a similar way, Skjong et al. (2005) and Vanem et al. (2007a,b) presented an environmental criterion equivalent to CAF. This is nothing new, but an incremental cost-effectiveness ratio to assess the case of accidental releases of oil to the marine environment that measures risk reduction in terms of the number of tonnes of oil averted. This criterion was named CATS (for "Cost to Avert one Tonne of Spilled oil") and its suggested threshold value was 60,000 USD/tonne. According to the CATS criterion, a specific Risk Control Option (RCO) for reducing environmental risk should be recommended for adoption if the value of CATS associated with it (defined as the ratio of the expected cost of implementing this RCO divided by the expected oil spill volume averted by it) is below the specified threshold, otherwise that particular RCO should not be recommended.

By definition, it is apparent that the above formulas use marginal costs. The idea of consideration of the marginal cost was also presented in Yamada (2009). The rationale of the approach as described in his paper is that a Risk Control Option (RCO) is considered to be cost effective if the following criterion is satisfied:

$$\mathrm{CATS} = \frac{\Delta C}{\Delta R} \le \mathrm{CATS}_{\mathrm{cr}} \tag{9}$$

where $\mathrm{CATS}_{\mathrm{cr}}$ is the critical value of the cost of averting a tonne of oil spilled (CATS). By definition this value is derived as follows:

$$\mathrm{CATS}_{\mathrm{cr}} = \frac{C_{\mathrm{ORG}} - C_{\mathrm{RCO}}}{W_{\mathrm{ORG}} - W_{\mathrm{RCO}}} = \frac{\Delta C_{\mathrm{ORG-RCO}}}{\Delta W_{\mathrm{ORG-RCO}}} = \frac{dC}{dW} \tag{10}$$

where the subscript "ORG" denotes the cost of the oil spill (C) and weight of the oil spill (W) before the implementation of the RCO and "RCO" denotes these after the implementation. Thus, the critical non-linear curve can be obtained by differentiating the cost curves that were derived by the regression analysis. The marginal cost curves were calculated in the previous section.

The authors want to stress out the importance of using the marginal cost in Cost Effectiveness Analysis for policy evaluation. In basic environmental economics, criteria for evaluating policies are based on their ability to achieve efficient and cost-effective reductions in pollution. According to basic textbooks (see for example Field, 2003), "efficiency" means the balance between abatement costs and damages. Furthermore, efficient policy is one that moves the society to, or near to, the point where marginal abatement costs and marginal damages are equal. Since that environmental damages cannot be measured accurately, the cost-effectiveness criterion is the most useful to be employed. As described in Field (2003), a policy is cost effective if "*it produces the maximum environmental improvement possible for the resources being expended or, equivalently, it achieves a given amount of environmental improvement at the least possible cost*".

Fig. 7 illustrates the incentive of owner to take precaution, or similarly the efficient point in implementing a regulation to prevent oil pollution. The figure is based on Tietenberg (1996) where he presents the case of water pollution and more specifically of oil spills. By forcing the vessel owner (or the Compensation Fund) to pay for the costs of an oil spill this creates the incentive for the owner to exercise care and for the regulator to implement control options to mitigate the pollution risk. Furthermore, the figure below illustrates the major characteristic of the legal system through liability law. The efficient point as described above given unlimited liability is Q^*. As described in Section 3, admissible claims cannot be paid in full, especially in the case of large spills, since the total compensation paid is limited. That is true for most compensation systems including IOPCFs but is also the case of the US Superfund. Thus, with limited liability the expected penalty is reduced and the level of precaution lowers, then the efficiency point is depicted as Q.

The precise way non-linear cost figures can be used in an FSA study is yet to be finalized, and it is among the subjects of discussion at the IMO how the volume-based approach will be integrated within the FSA method. The regression formulas derived above may be useful in estimating the total cost of oil spills and, thus, the benefit from pollution control. Environmental valuation is largely based on the assumption that individuals are willing to pay for environmental gains and, conversely, are willing to accept compensation for some environmental losses. Thus the benefits derived from pollution control are the damages prevented.

The general framework of Psaraftis (2008) might be useful in this regard, but other approaches may also be of interest. The approach assumes two scenarios: (a) the status quo, and (b) a scenario in which a specific RCO is applied to waterborne transport on a global basis. The purpose of this RCO is to reduce the risk of oil pollution, and this can be done by either reducing the probability of oil pollution or mitigating its consequences, or both.

Define E(TOT) as the expected annual total cost of oil spill worldwide of the status quo. This is the benefit to the society by averting the oil spill. To reduce this cost, a specific Risk Control Option (RCO) with a total cost of ΔK is introduced. So the new situation, with the specific RCO under consideration implemented, and for the specific way that this is carried out, will achieve a different (presumably lower) expected annual total cost of all spills worldwide, E_{RCO}(TOT). With the above in mind, once the E(TOT) and E_{RCO}(TOT) are known, the expected cost differential can be calculated as follows:

$$\Delta E(\mathrm{TOT}) = E(TOT) - E_{\mathrm{RCO}}(\mathrm{TOT}) \tag{11}$$

For use in Cost-Benefit Analysis the following can be said:

- The specific RCO under consideration is cost effective globally if its total cost $\Delta K < \Delta E(\mathrm{TOT})$, otherwise it is not.
- Among alternative RCOs that pass this criterion, the one that achieves the highest positive difference $\{\Delta E(\mathrm{TOT}) - \Delta K\}$ is preferable.

In other words, the decision rule implies that an RCO to be proposed for implementation should have a greater present value of benefits than costs. Note that this criterion guarantees that no activity confers more costs to the society than benefits, but it does not guarantee efficiency as described in the previous section. Furthermore note that this criterion has to be used in relation to the risk reduction that the RCO offers. Furthermore, what is interesting with this framework is that it is possible to combine fatality and environmental criteria. For more discussion on these matters the reader is referred to Psaraftis (2008).

An FSA study on crude oil tankers that used the threshold of 60,000 USD/tonne was conducted by project SAFEDOR and submitted to the IMO by Denmark, see IMO (2008). But this study is not yet under consideration by the IMO Group of Experts tasked to review all FSA studies, due to the fact that the CATS issue is still open. The non-linear regression formula described in this paper can be used instead of the single-value figure that was used in the above FSA study. The way this can be done is computationally straightforward, but caution should be exercised in the event trees of the FSA due to the non-linearity of the cost function. In that respect, if (for the sake of an example) spill volume is equally likely to be 1000 tonnes or 10,000 tonnes, one cannot base cost and benefit calculations on an average volume of 5500 tonnes.

7. Recent IMO developments and conclusions

At MEPC 60 (March 2010), a Working Group was formed, and after considerable debate, the majority of the group expressed its preference for a non-linear approach vis-à-vis a constant CATS threshold. Among the three non-linear regressions on the table (the one by Yamada, the one by Psarros et al., and the one proposed by the authors of this paper), the latter was considered as more conservative and was proposed as a basis for further analysis. To this effect, MEPC 60 agreed that in order to arrive at the recommended CATS criterion, the following should be considered (among other things):

(1) Member governments or interested organizations having their own additional data attempt to verify, and adjust as necessary the said regression formula by incorporating their additional (chosen) data in the analysis. In this connection, MEPC 60 agreed to invite the interested stakeholders to submit their data for each cost component and the results of their analysis for consideration.
(2) Following a more reliable establishment of the cost curve, a proposed CATS formula, to be used in the cost-effectiveness step of FSA can be established by introducing a margin or factor value (so-called assurance factor) still to be agreed representing society's willingness to prevent an accident rather than to simply neutralize its consequences.

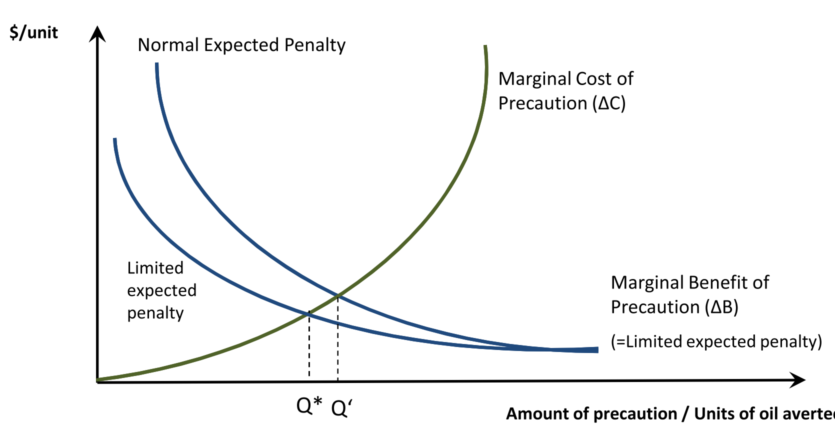

Fig. 7. Oil spill liability. Adopted from Tietenberg (1996).

(3) MEPC 60 invited member governments and interested organizations to use the non-linear cost function in FSA studies with a view to gain experience with its application and provide information to the IMO which may help to improve the proposed functions.

In conclusion, this paper has reported on recent analysis of oil spill cost data assembled by the International Oil Pollution Compensation Fund (IOPCF). Regression analyses of clean-up costs and total costs have been carried out, after taking care to convert to current prices and remove outliers. Indicative values of cleanup and total costs, as well as unit costs, marginal costs and median costs were derived. These analyses can be used, as described in Section 6, for calculating the cost of oils spills or the benefits of averting spills. However, note that the dataset analyzed contains spill ranging from 0.1 to 84,000 tonnes of which just 11 spills are above 5000 tonnes. There is evidence that the regression curves outside of these limits will overestimate the cost of larger spill and underestimate the cost of extremely smaller spills. Therefore, the formula produces better results when used for spill volumes within the range of the data used.

It is also hoped that these analyses and the points made in this paper can be further useful in the context of the discussion on environmental risk evaluation criteria in FSA, in the IMO, in the Cost-Benefit Analysis related to oil pollution and in the policy evaluation of measures that reduce the risk of oil pollution.

Acknowledgments

We would like to thank the Editor and the anonymous referees for their comments on a previous version of the manuscript.

References

Antweiler, W., 2009. Currencies of the World. University of British Columbia. http://fx.sauder.ubc.ca (Retrieved 2009-01-01).
Burgherr, P., 2007. In-depth analysis of accidental oil spills from tankers in the context of global spill trends from all sources. Journal of Hazardous Materials 140 (1–2), 245–256.
Cohen, M.A., 1986. The costs and benefits of oil spill prevention and enforcement. Journal of Environmental Economics and Management 13 (2), 167–188.
Etkin, D.S., 1999. Estimating cleanup costs for oil spills. In: Proceedings, International Oil Spill Conference, American Petroleum Institute, Washington, DC.
Etkin, D.S., 2000. Worldwide analysis of marine oil spill cleanup cost factors. Arctic and Marine Oil Spill Program Technical Seminar.
Etkin, D.S., 2001. Analysis of oil spill trends in the US and worldwide. In: Proceedings of the 2001 International Oil Spill Conference. Environmental Research Consulting, USA, pp. 1291–1300.
Etkin, D.S., 2004. Modeling oil spill response and damage costs. In: Proceedings of 5th Biennial Freshwater Spills Symposium, 6–8 April.
Field, B., 2003. Environmental Economics: An Introduction. McGraw-Hill, New York.
Friis-Hansen, P., Ditlevsen, O., 2003. Nature preservation acceptance model applied to tanker oil spill simulations. Journal of Structural Safety 25 (1), 1–34.
Giannakopoulos, Y., Bouros, D., Ventikos, N.P., 2007. Safety@Risk? In: Proceedings of the International Symposium on Maritime Safety, Security and Environmental Protection (SSE07), Athens, Greece, September 2007.
Grey, C., 1999. The cost of oil spills from tankers: an analysis of IOPC fund incidents. In: The International Oil Spill Conference 1999, 7–12 March 1999, Seattle, USA.
Goodman, C.S., 2004. HTA 11. Introduction to Health Technology Assessment. The Lewin Group, Falls Church, Virginia. http://www.nlm.nih.gov/nichsr/hta101/hta101.pdf.
Grigalunas, T.A., Anderson, R.C., Brown, G.M., Congar, R., Meade, N.F., Sorensen, P.E., 1986. Estimating the cost of oil spills: lessons from the Amoco Cadiz incident. Marine Resource Economics 1, 239–262.
Helton, D., Penn, T., 1999. Putting response and natural resource damage costs in perspective. In: Proceedings of the 1999 International Oil Spill Conference.
Hendricksx, R., 2007. Maritime oil pollution: an empirical analysis. In: Faure, M., Verheij, A. (Eds.), Shifts in Compensation for Environmental Damage. Springer Verlag.
IMO, 2007. Formal Safety Assessment: Consolidated Text of the Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process. MSC/Circ.1023–MEPC/Circ.392. London (MSC 83/INF.2).
IMO, 2008. Formal Safety Assessment on Crude Oil Tankers. Doc. MEPC 58/17/2 and MEPC 58/INF.2. Submitted by Denmark.
IOPCF, 2008. Annual report 2007. International Oil Pollution Compensation Funds, London, UK.
IOPCF, 2009. Annual report 2008. International Oil Pollution Compensation Funds, London, UK.
ITOPF, 2010. The International Regime for Compensation for Oil Pollution Damage. International Oil Pollution Compensation Funds, London, UK.
Jacobsson, M., 2007. The international oil pollution compensation funds and the international regime of compensation for oil pollution damage. In: Basedow, J., Magnus, U. (Eds.), Pollution of the Sea – Prevention and Compensation. Springer, Berlin, pp. 137–150.
Jean-Hansen, V., 2003. Skipstrafikken i området Lofoten – Barentshavet, Kystverket, Transportøkonomisk institutt, 644/2003, 2003 (in Norwegian. ISBN:82-480-0341-8).
Kontovas, C.A., Psaraftis, H.N., 2006. Assessing environmental risk: is a single figure realistic as an estimate for the cost of averting one tonne of spilled oil? Working Paper NTUA-MT-06-101, National Technical University of Athens, February. http://www.martrans.org.
Kontovas, C.A., Psaraftis, H.N., 2008. Marine environment risk assessment: a survey on the disutility cost of oil spills. In: 2nd International Symposium on Ship Operations, Management and Economics, Athens, Greece.
Kontovas, C.A., Psaraftis, H.N., 2009. Formal safety assessment: a critical review. Marine Technology 46 (1), 45–59.
Liu, X., Wirtz, K.W., 2006. Total oil spill costs and compensations. Maritime Policy and Management 33, 460–469.
Liu, W., Wirtz, K.W., Kannen, A., Kraft, A., 2009. Willingness to pay among households to prevent coastal resources from polluting by oil spills: a pilot survey. Marine Pollution Bulletin 58 (10), 1514–1521.
McCay, D.F., Rowe, J.J., Whittier, N., Sankaranarayanan, S., Etkin, D.S., 2004. Estimation of potential impacts and natural resource damages of oil. Journal of Hazardous Materials 107, 11–25.
Psaraftis, H.N., 2008. Environmental risk evaluation criteria. WMU Journal of Maritime Affairs 7 (2), 409–427 (19).
Psaraftis, H.N., Tharakan, G.G., Ceder, A., 1986. Optimal response to oil spills: the strategic decision case. Operations Research 34 (2), 203–217.
Psarros, G., Skjong, R., Endersen, O., Vanem, E., 2009. A perspective on the development of Environmental Risk Acceptance Criteria related to oil spills, Annex to International Maritime Organization document MEPC 59/INF.21, submitted by Norway.
Shahriari, M., Frost, A., 2008. Oil spill cleanup cost estimation – developing a mathematical model for marine environment. Process Safety and Environmental Protection 86 (3), 189–197.
Skjong, R., Vanem, E., Endresen, Ø., 2005. Risk Evaluation Criteria, SAFEDOR-D-4.5.2-2007-10-24-DNV-RiskEvaluationCriteria-rev-3.0. http://www.safedor.org.
Thébaud, O., Bailly, D., Hay, J., Pérez Agundez, J.A., 2005. The cost of oil pollution at sea: an analysis of the process of damage valuation and compensation following oil spills. In: Economic, Social and Environmental Effects of the Prestige Oil Spill de Compostella, Santiago. pp. 187–219.
Tietenberg, T., 1996. Environmental and Natural Resource Economics. HarperCollins College Publishers, New York, NY.
Vanem, E., Endresen, Ø., Skjong, R., 2007a. Cost effectiveness criteria for marine oil spill preventive measures. Reliability Engineering and System Safety 93 (9), 1354–1368.
Vanem, E., Endresen, Ø., Skjong, R., 2007b. CATS – cost-effectiveness in designing for oil spill prevention. In: PRADS 2007 Conference, Houston, USA, October.
Ventikos, N.P., Chatzinikolaoy, S.D., Zagoraios, G., 2009. The cost of oil spill response in Greece: analysis and results. In: Proceedings of International Maritime Association of Mediterranean, 12–15 October, Istanbul, Turkey.
White, I.C., Molloy, F., 2003. Factors that determine the cost of oil spills. In: International Oil Spill Conference 2003, Vancouver, Canada, 6–11 April.
Yamada, Y., 2009. The cost of oil spills from tankers in relation to weight of spilled oil. Marine Technology 46 (4), 219–228.