Determinants of Vessel-Accident Bunker Spillage

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Abstract

Although a substantial literature exists on vessel-accident oil spills, little attention has been given to bunker spills from non-oil-cargo vessels. This paper investigates determinants of the bunker spillage from non-oil-cargo vessel accidents. The amount of vessel-accident bunker spillage is posited to be a

function of vessel type, hull type, bunker fuel type, visibility at time of accident, type of vessel accident, and vessel operation phase. The function is estimated utilizing tobit regression and detailed data of individual non-oil-cargo vessel accidents that were investigated by the U.S. Coast Guard during the 8-year time period 2001-2008. The results suggest that a greater quantity of vessel-accident bunker fuel will be spilled when the vessel is abandoned, if the accident occurred at night, and when the vessel is adrift. Freight ships and offshore supply vessels spill more bunker fuel than passenger vessels in accidents. As expected, the size of a bunker spill from non-oil-cargo vessel accidents is smaller than the size of an oil-cargo spill from a tank barge accident.

Keywords

Bunker Spills, Bunker Convention, Vessel Accidents, Marine Pollution

DETERMINANTS OF VESSEL-ACCIDENT BUNKER SPILLAGE

Introduction

Oil spills are the most tangible evidence of pollution from shipping activities. Oils carried by ships are either cargo and/or fuel for their engines (i.e. bunker). While vessel-accident oil cargo spills can be much larger than vessel-accident bunker spills, the latter are more frequent than the former. Although oil-cargo vessels in the future will be required to have double hulls, the bunker tanks of non-oil-cargo vessels will not be required to be double hulled. The amount of bunker fuel carried by large ships can exceed 70,000 gallons which is larger than the average oil-cargo spill of an oil-cargo vessel accident (endnote 1). In 1978, the tanker 'Esso Bernicia' collided with the jetty at the Sullom Voe terminal in the Shetlands. The tanker was in ballast and 330,000 gallons of bunker oil escaped. On November 7, 2007, the containership 'Cosco Busan' collided with a bridge berth in San Francisco and spilled 54,000 gallons of bunker fuel into the bay.

Ships use a variety of fuels ranging from light distillates to heavy fuel oils. In general, large ships with slower running engines will use the heavier residual fuel marine bunker fuels and smaller ships with faster running engines will use distillates. It is important to note that ship bunkers are heavy fuel oils are highly viscous and slow to break down in the natural environment. A small quantity of bunker fuel can be disproportionately damaging to the marine environment and costly to clean up in comparison with light crude oil.

International conventions for the prevention of oil pollution in shipping have focused on oil-cargo spills as opposed to bunker spills. Examples of the former international conventions include: (1) the 1969 International Convention on Civil Liability for Oil Pollution Damage enhanced with 1992 Protocol (CLC 1992), (2) The 1971 International Convention on the Establishment of an International Fund for Oil Pollution Damage enhanced by the 1992 Protocol (The Fund Convention 1992), and (3) The International Convention for the Prevention of Pollution from Ships 1973 (MARPOL 1973/78). These three conventions do not consider bunker spills. The one exception is if bunker spills from oil tanker ships in laden. An international convention that does focus on ship bunker spillage is The 2001 Convention on Civil Liability for Bunker Oil Pollution Damage that was adopted by the International Maritime Organisation (IMO) on 23 March 2001 and entered into force on 21 November 2008.

The purpose of this paper is to investigate determinants of vessel-accident bunker spillage. Although numerous studies have investigated the oil spillage of oil-cargo vessel accidents (endnote 2), little attention has been given to investigating the bunker spillage of non-oil-cargo vessel accidents. Examples of the latter include Gucma and Przywarty (2007) that presented a model of oil spills due to ship collision and found that mean bunker spill is an exponential function of ship deadweight tonnage and Rogowska and Namiesnik (2010) that discussed the environmental effects associated with oil spills from shipping accidents. While the impacts of vessel bunker spillage are similar to those of vessel oil-cargo spillage, some impacts may differ. These differences should be considered by maritime policy makers in designing policies for minimizing vessel accidents and protecting the marine environment.

The remainder of the paper is organized as follows: Section 2 presents a model of the bunker spillage of ship accidents, followed by a discussion of the data in Section 3. Section 4 and 5 discuss tobit estimation results for the model and the adjusted tobit coefficients. Section 6 sets forth the conclusion.

The Model

As suggested by a number of relevant studies in the literature (endnote2), the amount of bunker spillage attributable to a vessel accident will depend on a number of factors such as vessel type, vessel size, vessel structural features, and weather and visibility conditions. Vessel-accident bunker spillage is posited to be a function of the time of accident, the type of vessel accident, vessel characteristics, visibility at time of accident, vessel operation phase and vessel hull material, i.e.,

vessel-accident bunker spillage = f (time of accident, type of vessel,
type of vessel accident, vessel characteristics,
visibility at time of accident,
vessel operation phase) (1)

The time of accident includes nighttime (NIGHT). The type of vessel accident includes an allision (ALLISION), a capsize (CAPSIZE), a collision (COLLISN), a damage to environment (ENVDAM), an emergency response (EMRESP), an explosion (EXPLODE), a fire (FIRE), a flooding (FLOODING), a grounding (GROUNDNG), a loss of power (LEPOWER), a loss of stability (STABILIT), a material failure (MATFAIL), a sinking (SINKING) and a loss of maneuverability (MANEUVER).

If the vessel strikes a stationary object, but not another ship, the accident is referred to as allision. A collision occurs when a vessel strikes or was struck by another vessel on the water surface. For an explosion (fire) vessel accident, the explosion (fire) is the initiating event for the accident, except were an equipment failure to the vessel is the initiating event, leading to the explosion (fire). A vessel flooding accident differs from a sinking accident in that flooding does not lead to a sinking of the vessel. In a grounding accident, the vessel is in contact with the sea bottom or a bottom obstacle. In an equipment failure accident, there is damage to equipment or equipment is missing.

Vessel characteristics include vessel size, age, flag, propulsion, and hull material. The gross tonnage (GROSSTON) of the vessel measures the vessel size. Since larger vessels carry larger amounts of bunker, the amount of vessel-accident bunker spillage for these vessels is expected to increase with the size of the vessel. Therefore, the a priori sign of GROSSTON is positive for volume of bunker spills. It is expected that the bunker spillage for an older vessel will be greater than that of a newer vessel, all else held constant, i.e., the a priori sign for vessel age (VSLAGE) and bunker spillage is positive. The flag of a vessel is distinguished by whether the flag is a U.S. flag or not. Given that the U.S. flag registry has some of the stricter vessel safety regulations among vessel registries, a negative relationship is expected between vessel accident bunker spillage and U.S. flag (USFLAG). The propulsion for vessels includes diesel engine (DIESEL), gasoline engine (GASENG), and turbine engine (TURBINE). Vessel hull type dummies are used to distinguish the material used for the cargo vessel. The hull material includes aluminium (ALUMHULL), fiberglass (GLASHULL), and wood (WOODHULL).

Visibility at time of accident is distinguished between whether it was nighttime (NIGHT) versus daytime at the time of the accident. Vessel operation phase is distinguished between whether the vessel was adrift (ADRIFT) or not. Vessel hull design is distinguished whether the vessel is a double-hull (DOUBHULL) or a single-hull vessel. A double-hull provides another layer protection for an oil tank in not spilling its cargo when involved in an accident. Most non-oil-cargo vessels are single-hulled.

Data

A principal challenge faced when attempting to examine vessel spillage is the absence of data. While for oil spills, plenty of data are publicly available, there are very few data available on bunker spills. Data collection therefore is an important focus of bunker spillage modeling.

Equation (1) is estimated utilizing detailed data of individual vessel accidents that were investigated by the U.S. Coast Guard during the 8-year time period 2001-2008 and extracted from the Coast Guard's Marine Information for Safety and Law Enforcement (MISLE) database. The U.S. Coast Guard compiles vessel casualty and pollution statistics and maintains a computer database of detailed records on vessel accident and pollution events in U.S. waters. The name and format of the database have changed over the years. Between 1981 and 1991, the vessel casualty database was called CASMAIN. From 1992 to 2001, vessel casualty and pollution records were incorporated into a larger database called Marine Safety Information System (MSIS). Since December 2001, the database has transitioned to the MISLE information system.

In the MISLE vessel accident data table, there is a long list of variables describing the vessel, time and location of each accident, and other related information (e.g., vessel type and flag). The MISLE vessel pollution table includes information on substance (e.g., oil and chemical) and volume spilled both in-water and out-water (e.g., spills on board or dock) as well as the total volume of liquid cargo or fuel that can potentially be carried by each vessel. We examine only in-water bunker spills.

Three MISLE data tables were merged to obtain a data set for vessel accident spill studies: the Vessel Event Table (MisleVslEvents), the Vessel Table (MisleVessel), and the Vessel Pollution Table (MisleVsPoll). The study focuses on vessels that are self-propelled, and thus using bunker fuel in their engines for propulsion, and are involved in the transport of either cargo or passengers. Accidents involving oil tankers were removed from the data as they carry most oil cargo. Freight barges were excluded from the dataset because they do not carry bunkers on board. Non-commercial vessels of cargo and passengers, such that recreational vessels, fish boats and tugboats, were also removed from the datasets.

Two datasets were used for the analysis of bunker spill vessel accidents. The first dataset includes freight ship (FRTSHIP), offshore supply vessel (OFFSHV), and passenger vessels (PASSENGR) only. The other dataset includes the three vessel types (FRTSHIP, OFFSHV, PASSENGR) and tank barge (TANKBARG). Since tank barge has oil cargo but no bunker fuel and the vessels (FRTSHIP, OFFSHV and PASSENGR) have bunker fuel but no oil cargo, we can investigate accident oil cargo spillage (via TANKBARG) versus accident bunker fuel spillage (via FRTSHIP, OFFSHV and PASSENGR).

Variables used in the equation estimation, their specific measurements, and descriptive statistics (mean and standard deviation) appear in Table 1. The means for the dependent variable, vessel-accident bunker spillage (BUNKSPIL), are 464.8 and 1,479.9 gallons for the three non oil cargo vessels and the three vessels with tank barge, respectively. The numbers of vessel accidents in the two datasets are 1,592, and 2,394, respectively.

Empirical Results and Managerial Insights

The effects of explanatory variables on the bunker spill size of vessel accidents, two models of Equation (1) are estimated separately using tobit regressions and the two different data sets: Model 1 is based on freight ships, offshore supply vessels and passenger ships only, Model 2 on the three types of vessel together with tank barges. The tobit model was first proposed by Tobin (1958), and refers to the linear regression model of censored dependent variable. For the spill data that we are considering, the data will be left-censored with a clustering at zero gallons, because spillage may not be observed on all vessel accidents. The tobit model is expressed for Equation (1) using a censored limit of zero as:

$$Y_i^* = \beta X_i + \varepsilon_i \quad , i=1,2,3,\ldots,N \tag{2}$$

$$Y_i = Y_i^* \text{ , if } Y_i^* > 0\,;$$

$$Y_i = 0 \text{ , if } Y_i^* \leq 0\,,$$

where N is the number of observations, Y_i the dependent variable, X_i a vector of independent variables, β a vector of estimated coefficients, and ε_i a normally and independently distributed error term with zero mean and constant variance. It is assumed that there is a latent variable equal to Y_i^* which is observable only when positive.

The results of the tobit estimations of the two models (Models 1 and 2) are shown in Table 2, which reports only significant explanatory variables (p-value <0.10). The goodness of fit for the tobit models seems reasonable, as indicated by the likelihood ratio statistic. The likelihood ratio statistic is computed as −2 [Log-Likelihood (restricted) − Log-Likelihood (unrestricted)]. This statistic of Models 1 and 2 have a limiting Chi-squared distribution with 8 and 10 degrees of freedom, respectively. Model 1 and Model 2 exceed their respective critical value 15.51 and 18.31, and thus the overall statistical fit of the models is quite good.

The sets of significant variables for Model 1 (column 2 of Table 2) are different from those for Model 2 (column 3 of Table 2). From Model 1, freight ship and offshore supply vessel tend to spill more bunkers than passenger vessels, because cargo ships usually carry more bunkers. Similarly, from Model 2, tank barge has a higher potential to spill more, because tank barges carry much more oils.

ABANDON is the only accident type statistically significant for both Model 1 and Model 2. An abandon, a vessel semi-submerged, is a principal hazard for non-oil-cargo vessels and tank barge. There are different reasons for a ship abandoned. However, a bunker tank of abandoned ship is often below the water level and it is extremely difficult to stop bunker leaking from an abandoned ship. Other accidents (e.g. loss of function, operating in emergency mode) do not often cause bunker spills.

The negative coefficient for VSLAGE in both Model 1 and Model 2 is inconsistent with expectation. The coefficient estimate suggests that the amount of bunker spills decreases with the age of vessels involved in a vessel accident.

The negative coefficients of DIESENG and STELHULL x DIESENG are consistent with expectation. That is to say, the results confirm that the bunker spills from ships would be less with steel hull material and diesel engine propulsion. Steel hull provides a good protection from bunker spills.

The coefficient of ADRIFT is positive in Model 2. Tank barges at adrift are associated with greater oil spill sizes.

Adjusted tobit Coefficients

Unlike ordinary least squares, tobit regression coefficients do not measure the correct change in a dependent variable from a change in an explanatory variable for non-zero observations of the dependent variable. Specifically, tobit coefficients can be adjusted to obtain such measures. McDonald and Moffitt (1980) showed that the change in the dependent variable (for its observations above a limit such as zero) from a change in an explanatory variable can be measured as the product of the explanatory variable's tobit coefficient and the adjustment factor “A”:

$$A = \{1 - [sf(s)/F(s)] - [f(s)2/F(s)2]\} \quad (3)$$

where s represents an evaluation (at the means of the explanatory variables) of the tobit equation divided by the equation's standard error; f(s) is the unit normal density; and F(s) is the cumulative normal distribution function. We refer to the product of “A” and a given tobit coefficient as the coefficient's “adjusted tobit coefficient”. See Green (2008) for the calculation of the adjusted tobit coefficients or marginal effects. In Table 3, only the adjusted tobit coefficients of the statistically significant explanatory variables (appearing in Table 2) are reported and discussed in the following paragraphs.

Model 1 shows that both variables FRTSHIP and OFFSHV have positive coefficients and are statistically significant, suggesting that freight ships and offshore supply vessels involved in accidents spill more bunker fuel than passenger vessels involved in accidents. Specifically, based upon the marginal effect results in Table 3, the bunker fuel spillage by freight ships and offshore supply vessels involved in accidents is 719 and 751 gallons more than that of passenger vessels involved in accidents.

Model 2 shows that the variables FRTSHIP, OFFSHV and PASSENGR all have negative coefficients and are statistically significant, suggesting that freight ships, offshore supply vessel and passenger vessels involved in accidents spill less bunker fuel than the oil cargo spilled by tank barges involved in vessel accidents. Specifically, based upon the marginal effect results in Table 3, the bunker fuel spillage by passenger vessels, offshore supply vessels and freight ships involved in accidents is 2,237, 1,099 and 1,004 gallons less, respectively, than the oil cargo spillage by tank barges involved in accidents.

The results of marginal effects also indicate that when the vessel is abandoned in an accident it is expected to spill close to 16 thousand gallons more bunker fuel than that when it is not abandoned (Model 1 in Table 3). The size of bunker spills is larger by over 900 gallons if the accident occurred at night.

Conclusion

Although numerous studies have investigated determinants of the oil spills of oil cargo vessels involved in accidents, determinants of vessel-accident bunker spillage have not been thoroughly investigated heretofore. This study has investigated determinants of vessel-accident bunker spills, utilizing vessel-accident data from the U.S. Coast Guard. Specifically, the tobit regression model and data on non-oil-cargo vessel accidents were utilized to investigate determinants of vessel-accident bunker spillage. The results of the investigation suggest that a greater quantity of bunker fuel will be spilled (e.g., over 10 thousand gallons) when the vessel is abandoned in an accident than when it is not abandoned. The size of bunker spills is larger if the accident occurred at night and when the vessel is adrift, ceteris paribus. Not surprisingly, the size of a bunker spill, on average, is smaller the oil-cargo spills of tank barges. Freight ships and offshore supply vessels involved in accidents spill more bunker fuel than passenger vessels involved in accidents.

The investigation of determinants of vessel-accident bunker spillage found in this study is important, since: (1) non-oil-cargo vessels are more numerous than oil-cargo vessels, (2) bunker tanks are single-hulled, and (3) bunker fuel is denser and more harmful to the environment than oil cargo. The study is an initial step to improve our understanding of bunker spills which is crucial for the development of relevant pollution control measures. The empirical results presented here will be useful for future evaluation of the Bunker Convention that has been enforced since November 2008.

Endnotes

1. The world consumption of marine bunkers in 2002 was 149 million tones (Endresen et al., 2007).

2. See Anderson and Talley (1995), Cohen (1995), Jin, Kite-Powell and Broadus (1994), Jin and Kite-Powell (1995), Jin and Kite-Powell (1999), Talley (2000), Talley, Jin and Kite-Powell (2001), Goulielmos (2001), Talley, Jin and Kite-Powell (2004), Talley, Jin and Kite-Powell (2005), Dalton and Jin (2010), and Yip, Talley and Jin (2011).

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Table 1: Variable Definition and Descriptions Statistics

Variables	Description and Measurement	Mean (Standard Derivation)	Mean (Standard Derivation)
		Model 1	Model 2

		Frtship Offshv Passengr	Frtship Offshv Passengr Tankbarg
Dependent variable			
BUNKSPIL	Gallons of bunker spilled in water	464.8 (8212.9)	1,474.9 (14,282.4)
Explanatory variables			
Time of accident			
YEAR	Year 2001-2008	2004 (1.5)	2004 (1.5)
Type of vessels			
FRTSHIP	1 if freight ship, 0 otherwise	0.300 (0.459)	0.200 (0.400)
OFFSHV	1 if offshore supply vessel, 0 otherwise	0.276 (0.447)	0.183 (0.387)
PASSENGR	1 if passenger ship, 0 otherwise	0.424 (0.494)	0.282 (0.450)
TANKBARG	1 if tank barge, 0 otherwise		0.335 (0.472)
Type of vessel accident			
ABANDON	1 if an abandon, 0 otherwise	0.007 (0.083)	0.005 (0.068)
ALLISION	1 if an allision, 0 otherwise	0.009 (0.093)	0.009 (0.093)
CAPSIZE	1 if a capsize, 0 otherwise	0.003 (0.050)	0.002 (0.041)
COLLISN	1 if a collision, 0 otherwise	0.001 (0.035)	0.005 (0.068)
ENVDAM	1 if a damage to environment, 0 otherwise	0.844 (0.363)	0.853 (0.355)
EMRESP	1 if an emergency response, 0 otherwise	0.007 (0.083)	0.010 (0.098)
EXPLODE	1 if an explode, 0 otherwise	0.001 (0.025)	0.002 (0.041)
FIRE	1 if a fire, 0 otherwise	0.003 (0.056)	0.003 (0.058)

FLOODING	1 if a flooding, 0 otherwise	0.022 (0.147)	0.015 (0.123)
GROUNDNG	1 if a grounding, 0 otherwise	0.016 (0.124)	0.014 (0.118)
LEPOWER	1 if a loss of power, 0 otherwise	0.003 (0.056)	0.002 (0.046)
STABILIT	1 if a loss of stability, 0 otherwise	0.001 (0.035)	0.001 (0.029)
MATFAIL	1 if a material failure, 0 otherwise	0.045 (0.206)	0.053 (0.223)
SINKING	1 if a sinking, 0 otherwise	0.027 (0.162)	0.018 (0.134)
MANEUVER	1 if a loss of maneuverability, 0 otherwise	0.008 (0.087)	0.005 (0.071)
Vessel characteristics			
GROSSTON	Vessel size in gross tonnage [gross tons]	8,883.3 (17,707.3)	6,687.6 (14,862.4)
VSLAGE	Vessel age [years]	21.10 (14.60)	23.10 (14.70)
USFLAG	1 if a U.S. flag vessel, 0 otherwise	0.720 (0.449)	0.814 (0.389)
DIESENG	1 if the vessel is under diesel population, 0 otherwise	0.837 (0.369)	0.600 (0.500)
GASENG	1 if the vessel is under gas population, 0 otherwise	0.001 (0.025)	0.0004 (0.0204)
TURBINE	1 if the vessel is under turbine population	0.023 (0.149)	0.015 (0.122)
ALUMHULL	1 if aluminum hull, 0 otherwise	0.132 (0.338)	0.088 (0.283)
GLASHULL	1 if fiberglass hull, 0 otherwise	0.075 (0.264)	0.050 (0.218)
STELHULL	1 if steel hull, 0 otherwise	0.651 (0.477)	0.767 (0.423)
WOODHULL	1 if wood hull, 0 otherwise	0.075 (0.264)	0.050 (0.218)
DOUBHULL	1 if double-hull design, 0 otherwise	0.001 (0.025)	0.079 (0.27)
STELHULL x DIESENG	1 if steel hull and the vessel is under diesel population, 0 otherwise	0.600 (0.500)	0.400 (0.5)
Visibility at time of accident			

NIGHT	1 if nighttime, 0 otherwise	0.260 (0.439)	0.289 (0.453)
Vessel operation phase			
ADRIFT	1 if the vessel sets adrift , 0 otherwise	0.003 (0.05)	0.002 (0.046)
Observations		1,592	2,394

Table 2: Vessel-accident bunker spillage: tobit regression estimates

	Model 1	Model 2
	Frtship Offshv Passengr	Frtship Offshv Passengr Tankbarg
	Coefficient (t-statistic)	Coefficient (t-statistic)
Dependent variable		
BUNKSPIL		
Explanatory variables		
Type of vessel		
FRTSHIP	1,408*** (2.63)	-1,895** (-1.89)
OFFSHV	1,471** (2.42)	-2,075** (-1.76)
PASSENGR		-4,224*** (-5.28)
Type of vessel accident		
ABANDON	31,059*** (12.88)	25,726*** (5.86)
ENVDAM		-6,172*** (-6.66)
EMRESP		-6,043** (-1.94)
SINKING		-4,274** (-1.83)
Vessel characteristics		
GROSSTON	0.02** (1.8)	

VSLAGE	-28** (-1.89)	-62*** (-3.07)
DIESENG	-1,102** (-1.67)	
STELHULL x DIESENG	-1,190** (-2.04)	-1,508** (-1.74)
Visibility at time of accident		
NIGHT	958** (2.1)	
Vessel operation phase		
ADRIFT		37,461*** (5.87)
Constant	911** (1.26)	436** (2.29)
Number of Observations	1,592	2,394
Log-likelihood (unrestricted)	-15,905.4	-25,246.73
Log-likelihood (restricted)	-15,999.5	-25,335.43
Likelihood ratio statistic	188.08	177.4

Note: *** significant with p-value <0.01

** significant with p-value <0.05

* significant with p-value <0.10

Table 3: Vessel-accident bunker spillage: tobit regression estimates

	Frtship Offshv Passengr	Frtship Offshv Passengr Tankbarg
	Coefficient	Coefficient
Dependent variable		
BUNKSPIL		
Explanatory variables		
Type of vessel		
FRTSHIP	719 (2.63)	-1,004 (-1.89)
OFFSHV	751 (2.42)	-1,099 (-1.76)

PASSENGR		-2,237 (-5.26)
Type of vessel accident		
ABANDON	15,863 (12.49)	13,626 (5.83)
ENVDAM		-3,269 (-6.62)
EMRESP		-3,201 (-1.94)
SINKING		-2,264 (-1.83)
Vessel characteristics		
GROSSTON	0.01 (1.8)	
VSLAGE	-14 (-1.89)	-33 (-3.07)
DIESENG	-563 (-1.66)	
STELHULL x DIESENG	-608 (-2.04)	-799 (-1.74)
Visibility at time of accident		
NIGHT	489 (2.09)	
Vessel operation phase		
ADRIFT		19,842 (5.84)
Constant	465 (1.25)	231 (2.29)

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