Estimating the Size of Oil Tanker Spills

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Abstract

This paper estimates the determinants of the size of oil tanker spills. In the literature, spill size has been estimated but the results are not very strong. A review of the existing results is provided and the determinants of spill size using a sample selection model are estimated. Estimates from a Tobit regressions are also given to serve as a basis of comparison with the earlier work. One important finding is that groundings and collisions result in larger spills if there is a spill, but the likelihood that there will be a spill due to a grounding or collision is very low. Tanker size is found to have only a marginal effect on the probability of a spill and a dubious effect on spill size. US flag tankers and new tankers are found to have a lower probability of causing spills compared to foreign flag and old tankers, respectively. US flag tankers do not have smaller spills when type of cargo variables are included in the analysis. So it is not straightforward to claim that US flag tankers have smaller spills due to stricter regulations.

1 Introduction

More than one-third of the total crude oil and products transported worldwide by tankers passes through US waters [1]. The end result of this traffic is about 1500 spills a year[2]. Most of the spills occur during cargo transfers and are quite small in size (see Figure 1) but the bulk of oil spilled annually is due to a few very large spills. Effective policymaking requires an understanding of how vessel and voyage characteristics are related to the size of spills. This understanding will aid in designing policies that are specifically targeted at reducing the large spills that can cause public outrage. The United States Coast Guard (USCG) lists the reduction in the number of large and medium spills by 50 percent as one of its performance goals. This paper aspires to uncover the links between the size of oil spills and available voyage information, to help policymakers exploit these links. The determinants of size of oil spills are estimated utilizing data on all spills in US navigable waters from 1985 through 1991. The effects of vessel characteristics, such as flag, size and age, on spill size are investigated, as well as how spill size differs between groundings, and accidents due to adverse weather or improper maintenance.

In the next section a review of the literature is provided, followed by a description of the data. Section 4 describes the model and the methodologies employed to estimate the different versions. Section 5 discusses the results and is followed by the conclusion of the paper.

[1] National Research Council 1991, p.11

[2] The United States Coast Guard.

2 Literature Review

During its voyage or during cargo operations, an oil tanker may experience several mishaps. It may collide into another vessel or run aground; there may be a fire or explosion; or a machine or valve may break down. Anything that goes wrong during a voyage or during cargo transfers that is serious enough to be reported to the United States Coast Guard (USCG) is hereafter referred to as a tanker accident. If the tanker is carrying oil at the time of the accident, oil may be released into the water, i.e. an oil spill may occur.

The accident rate of tankers has been extensively researched. Examples include work by Beyer and Painter (Beyer & Painter 1977), Meade et al. (Meade *et al.* 1981) and (Meade, LaPointe, & Anderson 1983), Le Blanc and Rucks (Le Blanc & Rucks 1995), Stewart and Kennedy (Stewart & Kennedy 1977) and Groenhuis (Groenhuis 1981). The probability that an accident results in a spill has been investigated in three papers (Devanney & Stewart 1974),(Epple & Visscher 1984),(Goodstein 1992). Goodstein is interested in spill rates on days of the week and finds a significant Saturday effect (Goodstein 1992). Devanney and Stewart estimate spill rate assuming an underlying Poisson process (Devanney & Stewart 1974). Epple and Visscher cannot estimate spill rate but make inferences based on their estimates for spill size (Epple & Visscher 1984).

Tere are two main approaches to investigating the factors that influence the size of an oil spill. Some researchers have looked at the size of a spill given that a tanker accident has occurred, and others have focused on spill size given that a spill has occurred. An example for the former is a paper by Anderson and Talley where they analyze the determinants of spill size conditional on a tanker accident having occured in a Tobit model, utilizing detailed data on individual vessel accidents in US waters from 1984 to 1989 (Anderson & Talley 1995). They find that spill size is greater for adrift tankers and for spills in coastal waterways and lower for large tankers and US flag tankers.

Ketkar and Babu estimate spill size in a linear regression model using only spills that are 4000 gallons or more (Ketkar & Babu 1997). They find vessel size to be positively correlated with spill size but this result cannot be generalized because it is based on a biased sample.

Two papers try to estimate the probability of a spill and the size of a spill. Devanney and Stewart assume a Poisson process for spill incidence and a gamma distribution for spill size (Devanney & Stewart 1974). Epple and Visscher (Epple & Visscher 1984) specify a linear relationship between the independent variables (vessel size, price of oil, level of Coast Guard enforcement, and spill variance) and the dependent variables (the natural logarithm of the probability of a spill and the natural logarithm of spill size). They use a two-step Tobit procedure to estimate spill size[3] and then based on these estimates make inferences about the probability of a spill. Their results, which utilize data from 1974-1977, show that spill size increases with vessel size, and decreases with the price of oil and increased enforcement. Price of oil ceases to be significant when spills of 1 gallon are eliminated. Cohen reestimates their results, with a more detailed treatment of Coast Guard enforcement (Cohen 1987).

In this paper, the determinants of spill size are estimated in a sample selection model. This approach awknowledges the dependency of spill size on the probability of spill occurence and is thus a superior approach than estimating the two equations separately as in Devanney

[3] They first estimate the mean spill size as a function of the price of oil, the level of enforcement and vessel size in each Coast Guard district. The resulting estimated variances are then used to estimate mean spill size as a function of spill variance in addition to the above variables in the second step.

and Stewart (Devanney & Stewart 1974), and Epple and Visscher (Epple & Visscher 1984). The only work that has specified the determinants of spill frequency and spill size has used the same independent variables in both equations. As much as data permits, we adopt the same approach. All the variables we consider could affect both spill size and spill probability. If we think of the sample selection as an omitted variable problem, it is natural to assume that the things we failed to account for in estimating spill probability would also be missing from the spill size equation, hence the dependency of spill size on spill probability. A Tobit model is also estimated to serve as a comparison to previous work.

A detailed pollution database is utilized and it is possible to distinguish crude oil spills from other spills. This is shown to improve the results. Possibly due to data limitations, crude oil spills and product spills have not previously been differentiated even though traffic patterns and tanker sizes vary significantly. Tankers carrying oil products exhibit more frequent stops and travel from refineries to markets. Crude oil tankers are generally larger, their voyages are longer, they usually have one destination and they travel between refineries and production points. It is not possible to distinguish crude oil spills from those of oil products in the selection stage, but they are treated separately in estimating spill size once a spill occurs. The data are partially from the CASMAIN Vessel Casualty Database which is the source of the data Anderson and Talley analyzed in their paper (Anderson & Talley 1995). In the next section a detailed description of the complete dataset is provided.

3 Data

Detailed data on oil spills by tankers in US waters from 1985 to 1991 is extracted from casualty and pollution databases maintained by the USCG. A casualty may result in a spill, but not every spill is due to a casualty. If a tanker casualty causes a spill, this incident is entered in both databases. Data on casualties that did not result in a spill were extracted from the casualty database and combined with the data from the pollution database. Of the substances tankers had been reported to spill, those classified as soot, ballast water, edible oils, solid waste and non-polluting material were eliminated. In general tankers that transport products will transport many different products on any given voyage. So an accident that results in a spill by one such tanker may involve more than one type of substance spilled. The quantity spilled when more than one substance was spilled by a tanker was calculated by adding all the quantities spilled in the accident. If this information was missing for one substance, this spill was excluded from the analysis. The resulting sample has 2263 tanker accidents out of which 784 have caused a spill. The case numbers for these incidents are provided in Appendix B[4]. For each accident, information on the type of accident is available in the form of dummy variables for grounding, collision, adverse weather and improper maintenance. These are the classifications used by the USCG. The age, size and flag of each tanker is also included.

It was necessary to extract information from three different files. The size and age of tankers were only reported in the CASMAIN database (See Appendix A). The identification numbers of the vessels (VIN) involved were available in both the CASMAIN database and the Pollu-

[4]The data is also available in electrocin format on request from the author.

Table 1: Variables and Their Measurement
Oil Spills by Tankers from 1985 to 1991

	Measurement
Dependent Variables	
Spill Size (SPILL)	Gallons
Type of Accident Variables	
Grounding (GRNDING)	1 if a grounding, 0 otherwise
Adverse Weather (WEATHER)	1 if spill was due to adverse weather, 0 otherwise
Improper Maintenance(IMPMAINT)	1 if spill was due to improper maintenance, 0 otherwise
Collision (COLLISION)	1 if a collision, 0 otherwise
Operating Condition Variables	
Cargo operations (CARGO)	1 if spill occurred during cargo operations, 0 otherwise
Underway (UNDERWAY)	1 if vessel was underway, 0 otherwise
Vessel Characteristic Variables	
Size of Vessel (SIZE)	Gross Tons
Age of Vessel(AGE)	Years
Flag of Vessel(US)	1 if a US flag vessel, 0 if a foreign flag vessel

tion Vessel Supplement File (see Appendix A). Size and age of tankers involved in pollution incidents were extracted by matching the vessel identification numbers in the two files. The entries in the USCG database are for size and the year the vessel was built. When a vessel is retrofitted, this date is entered as the year built. So for some vessels the database produces multiple years as the year the vessel was built. The dates of entries in all files were available so age was computed based on the year built that was before and closest to the date of the spill when the database provided multiple years. However, vessels are in the database when they are involved in a casualty or a pollution incident. So if a vessel was not involved in a casualty after it was retrofitted but was involved in a pollution incident then the age variable would not reflect the fact that the vessel had recently undergone a major reconstruction.

Definitions of all variables are provided in Table 1. Descriptive statistics for crude oil spills only and for all oil spills are provided in Tables 2 and 3.

There were very few observations for collisions that resulted in crude oil spills so this infor-

Table 2: Descriptive Statistics
Crude Oil Spills by Tankers from 1985 to 1991

	Mean	Standard Deviation
Dependent Variable		
SPILL	24679	189056
Type of Accident Variables		
GRNDING	0.066	0.25
WEATHER	0.027	0.16
IMPMAINT	0.031	0.17
Vessel Characteristic Variables		
SIZE	52519	24591
AGE	13.37	6.21
US	0.547	0.50

mation is not given in the summary. The average size of crude oil spills was 25,000 gallons compared to 10,000 gallons for crude oil and products combined. 55 percent of the tankers that caused crude oil spills are US flag tankers. This figure overrepresents the share of US flag tankers in crude oil spills because missing data is a problem for a greater proportion of foreign flag tankers. US flag tankers represented 35 percent of tankers that caused crude oil spills before spills with missing data were eliminated. For minor spills, reports are not carefully kept, only readily available data is recorded, which introduces a bias against foreign flag tankers. The age variable introduces an even greater bias against foreign flag tankers. In cases of minor pollution, nothing is entered into the casualty database. Since the age variable needs to be extracted from the casualty database, only those foreign flag tankers that were involved in a casualty in the time period can be included in the sample.

US flag tankers caused 51 percent of crude oil and product spills in the sample. It is surprising to see the proportion of US flag tankers drop when the sample is expanded to include spills of petroleum products. Figure 2 summarizes the commercial movements of crude oil and products in US waters. 70 percent of the waterborne commerce of petroleum products was domestic in 1985. The ratio had dropped slightly to 64 percent by 1990[5]. The corresponding figures for the waterborne commerce of crude oil were 54 percent and 36 percent[6]. Because of the Jones Act all domestic waterborne trade has to be by US flag vessels. The share of US flag tankers in waterborne foreign trade was around 3% for this time period[7]. These figures suggest that the probability of having a spill for US flag vessels and foreign flag vessels is about the same.

The average age of vessels involved in crude oil spills is 13 years compared to 15 years for crude oil and product spills. It is not difficult to explain the increase in average age when product spills are combined with crude oil spills. Most of the waterborne commerce in petroleum products is domestic so has to be done with US flag vessels and the US tanker fleet is older than the world average[8].

The average size of tankers involved in crude oil spills is 50,000 gross tons, compared to 30,000 gross tons for crude oil and product spills. 7 percent of the spills were caused by groundings and 3 percent by collisions. 43 percent of the spills happened during cargo operations. Tankers usually unload the cargo outside the port since not all ports are deep enough for larger tankers. Cargo may be unloaded to barges and then taken to shore or tankers may be connected to underwater pipelines to unload. Valve failures are a common cause of spills during these operations. However, these spills are generally contained in a relatively short period of time.

[5]Bureau of Transportation Statistics
[6]Bureau of Transportation Statistics
[7]US Bureau of Census
[8]The average age of US flag tankers in 1985 was 19 years, and the world average was 13 years.

Table 3: Descriptive Statistics
Oil Spills by Tankers from 1985 to 1991

	Mean	Standard Deviation
Dependent Variable		
SPILL	10008	107874
Type of Cargo Variables		
CRUDE	0.276	0.45
FUELOIL	0.182	0.39
DIESEL	0.063	0.24
Type of Accident Variables		
GRNDING	0.068	0.25
WEATHER	0.022	0.15
IMPMAINT	0.024	0.15
COLLISION	0.025	0.16
Operating Condition Variables		
CARGOOPS	0.432	0.5
UNDERWAY	0.120	0.33
Vessel Characteristic Variables		
SIZE	31938	24944
AGE	14.93	10.56
US	0.506	0.50

4 Estimation

In this section a model for estimating spill size is developed. There are different approaches one can take. One can specify a distribution for spill size such as lognormal, gamma or exponential, and estimate the model by maximum likelihood as in papers by Devanney and Stewart (Devanney & Stewart 1974), and Epple and Visscher (Epple & Visscher 1984). There are two disadvantages to this approach: model misspecification would produce inconsistent estimates and the information content of the accidents that did not cause a spill is ignored[9]. Alternatively, one might combine the information on accidents that did not cause a spill with those that did within a Tobit framework as in Anderson and Talley (Anderson & Talley

[9] We estimated the distribution of crude oil spills with maximum likelihood for these three distributions and have found the parameter estimates sensitive to model specification. These parameter estimates are available from the author upon request.

1995). However, if we believe there is a fundamental difference between incidents that caused a spill and those that did not, bundling all the information may not prove fruitful[10].

Here, we adopt a methodology that enables us to use information on spills as well as information on accidents that did not result in spills yet can uncover the fundamental differences between them. We estimate the probability that a spill would occur given an accident and then estimate spill size given that a spill has occurred. If we belive that factors that affect wheteher there will be a spill or not for an accident, also influence the size of the spill if there is one, then there is a sample selection effect as described below.

Let z_i^* be the probability that there will be a spill. This probability is not observed, we only observe whether a spill occurs or not. Let $z_i = 1$ if a spill occurs and $z_i = 0$ if it doesn't. This is described in the selection equation:

$$z_i^* = w_i\gamma + v_i, \quad z_i = 1 \quad if\ z_i^* > 0; \tag{1}$$

$$z_i = 0 \quad otherwise.$$

where w_i is a vector of independent variables, γ is a vector of coefficients and v_i is an independent error term.

Determinants of spill size given that an accident has resulted in a spill is given by the outcome equation:

$$y_i = x_i\beta + \epsilon_i, \quad observed\ only\ if\ z_i = 1. \tag{2}$$

[10]We estimated a Tobit model. These results are discussed in some detail in Section 5.1.

y_i is the natural logarithm of spill size in gallons, x_i is a vector of independent variables, β is a vector of coefficients and ϵ_i is an error term. v_i and ϵ_i are distributed independently of w_i. Since spill size is observed only when $z_i = 1$, and since $z_i = 1$ when $v_i > -w_i\gamma$; for $z_i = 1$ the outcome equation becomes:

$$y_i = x_i\beta + \lambda(w_i\gamma) + u_i, \tag{3}$$

where

$$\lambda(w_i\gamma) = E[\epsilon_i|v_i > -w_i\gamma] \tag{4}$$

so that $E[u_i|w_i] = 0$. The additional term in (3) is referred to as the "correction" term. It corrects (2) by including the possible correlation between v_i and ϵ_i. $E(\epsilon_i) \neq E(\epsilon_i|v_i)$ and the outcome equation is relevant only when $E(\epsilon_i|v_i > -w_i\gamma)$.

When the joint distribution of v_i and ϵ_i is assumed to be bivariate normal, $\lambda(w_i\gamma)$ is proportional to the inverse Mill's ratio:

$$(v_i, \epsilon_i) \sim N(0, 0, 1, \sigma_\epsilon, \rho) = \beta_\psi \psi_i \tag{5}$$

$$\lambda(w_i\gamma) = \rho\, \sigma_\epsilon\, \phi(w_i\gamma)/\Phi(w_i\gamma) \tag{6}$$

where $\phi(w_i\gamma)$ is the standard normal density function evaluated at $w_i\gamma$ and $\Phi(w_i\gamma)$ is the cumulative distribution function evaluated at $w_i\gamma$.

The model is estimated using the procedure proposed by Heckman, estimating the selection equation by maximum likelihood to get consistent estimates of γ, using the representation

$$P(z_i = 1|w_i\gamma) = E(z_i|w_i\gamma) = \Phi(w_i\gamma), \tag{7}$$

and then estimating the outcome equation by least squares having constructed $\hat{\psi}_i$ (Heckman 1979). The covariance matrix for $(\hat{\beta}, \hat{\beta}_\psi)$ is:

$$V = \hat{\sigma}_\epsilon^2 (X_*'X_*)^{-1}(X_*'(I - \hat{\rho}^2\hat{\Delta})X_* + Q)(X_*'X_*)^{-1} \tag{8}$$

where $X_* = (X, \hat{\Psi})$ is the matrix of independent variables for equation 3 and $(I - \hat{\rho}^2\hat{\Delta})$ is a diagonal matrix with $(1 - \hat{\rho}^2\hat{\delta}_i)$ on the diagonal. $\hat{\delta}_i$ is defined as

$$\hat{\delta}_i = \hat{\psi}_i(\hat{\psi}_i + w_i\hat{\gamma}) \tag{9}$$

$$\hat{\sigma}_\epsilon^2 = \frac{1}{n}\epsilon'\epsilon + \beta_\psi^2 \frac{1}{n}\sum \hat{\delta}_i, \tag{10}$$

and

$$Q = \hat{\rho}^2(X_*\hat{\Delta}W)\hat{\Omega}(W'\hat{\Delta}X_*). \tag{11}$$

W is the matrix of independent variables for the selection equation 1 and $\hat{\Omega}$ is the estimated covariance matrix of $\hat{\gamma}$.

5 Discussion of Results

Before discussing the results from the model described above, the estimates from two different Tobit regressions are presented and discussed. These results are presented as a basis of comparison with the work of Anderson and Talley. Then the estimates from the sample selection model are introduced and compared with previous findings.

5.1 Tobit Estimates

Anderson and Talley estimate the determinants of real value of cargo spilled on data from 1984-1989(Anderson & Talley 1995). They include enforcement expenditures by the USCG and the price of oil, as well as type of accident variables and vessel characteristics. They find that larger vessels and US flag vessels have smaller spills. They do not find any of the accident type variables significant. A sample was constructed to estimate the determinants of real value of cargo spilled (VOS) to compare with Anderson and Talley's results. From the CASMAIN database, all tanker spills with known value of cargo spilled were extracted for the time period 1985 to 1991. If cause of accident, time of day, flag or size of vessel were unknown or missing these incidents were excluded from the analysis. The resulting sample had 1218 observations, only 33 of which had a positive value of cargo spilled[11]. The descriptive statistics on the sample are given in Table 4. 70 percent of the incidents involved US flag vessels. The average age was 16 years, and average size 32,000 gross tons. 35 percent of the incidents were groundings and 18 percent were collisions.

[11] The data is available from the author upon request.

Table 4: Descriptive Statistics
Value of Cargo Spilled by Tankers from 1985 to 1991

	Mean	Standard Deviation
Dependent Variable		
RealVOS	6063	93267
Type of Accident Variables		
GRNDING	0.251	0.43
WEATHER	0.019	0.14
FIRE	0.038	0.19
COLLISION	0.189	0.39
Operating Condition Variables		
WIND	11.89	12.08
NIGHT	0.347	0.48
Vessel Characteristic Variables		
SIZE	32059	27746
AGE	15.93	11.23
US	0.700	0.46

This sample compares very well with that of Anderson and Talley. In their sample 74 percent of the vessels were US flag, average age was 16 and average size was 30,000. Their sample had 3.8 percent positive cargo spillage compared to 2.7 percent for this sample. The vessel characteristic variables, and collision and fire among accident type variables are the common variables. Estimates from a Tobit regression on real value of cargo spilled are presented in Table 5.

US flag vessels are found to have significantly smaller spills conditional on an accident which confirms Anderson and Talley's findings. There is a discrepancy in the significance of size and age variables, however. The age variable but not the size variable is found significant, whereas Anderson and Talley find the size variable significant and not the age variable. There is a negative correlation between age and size [12], however, the exclusion of the age variable does not produce a significant size effect. The type of accident variables are not

[12] Newer vessels tend to be larger.

Table 5: Tobit Estimates
Estimation Results for Value of Cargo Spilled

Dependent Variable	Spill Size	Value of Cargo Spilled
Type of Accident Variables		
GRNDING	-117907.2***	117670
	(13141.59)	(149826)
WEATHER	11725.46	428610
	(23668.7)	(441786)
FIRE	NA	327277
	NA	(278273)
COLLISION	-131121.4***	-213421
	(17472.57)	(226068)
IMPMAINT	-1051.98	NA
	(23149.03)	NA
Operating Condition Variariables		
WIND	NA	-11294
	NA	(7312)
NIGHT	NA	61570
	NA	(135807)
Vessel Characteristic Variables		
SIZE	-0.0113	-0.436
	(0.1333)	(2.66)
AGE	515.85	14442**
	(356.66)	(5749)
US	-55752.81***	-391410**
	(7666.05)	(154140)
CONSTANT	-40956.58***	11543922***
	(8824.74)	(297882.5)
N	2263	1218
Log Likelihood	-10829.798	-588.69

*** significant at the 1% level.
** significant at the 5% level.
* significant at the 10% level.

found to be significant again confirming prior findings.

Estimates from Tobit regression on spill size conditional on an accident having occurred are also presented in Table 5. The dependent variable here is spill size in gallons. The significant variables in this regression are the grounding, collision and flag variables indicating that when the accident type is grounding or collision, and/or the tanker is a US flag tanker, the spill size is on average smaller. The two vessel characteristic variables, size and age are not found significant. An important difference between the samples the two Tobit regressions were based on, is the ratio of spills to all accidents. In the sample entirely based on the CASMAIN database, 2.7 percent of accidents have spills. In the sample that combines data from the CASMAIN database with the data from the USCG pollution database, 35 percent of accidents cause a spill. Most of the spills in the latter sample are spills during cargo transfers, which were not recorded in the CASMAIN database.

5.2 Estimates from the Sample Selection Model

Regression results from the sample selection model with normal errors are presented in Table 6. The significant variables in the selection equation are the grounding, collision, flag and age variables. The first three variables indicate a smaller probability of spill, as opposed to the age variable that indicates a higher probability of spill.

Table 7 and Table 8 highlight these results. Table 7 reports the probability that there will be a spill conditional on an accident for vessels of different size and age for both foreign flag and US flag vessels. The probability of a spill increases slightly with age and decreases with size. For 15 year old large vessels, the probability of a spill given that an accident has occured is

Table 6: Estimation Results for Oil Spills

Explanatory Variables	Probit	log Spill Size	log Spill Size
Type of Accident Variables			
GRNDING	-1.8986***	24.3496***	14.5859***
	(0.1242)	(6.2962)	(4.8410)
COLLISION	-1.4921***	17.3673***	10.6938***
	(0.1364)	(4.8117)	(3.6452)
WEATHER	-0.0503	0.3504	-0.0322
	(0.2049)	(1.8171)	(1.1179)
IMPMAINT	0.0068	-0.0909	-0.0542
	(0.2057)	(1.7425)	(1.0719)
Vessel Characteristic Variables			
SIZE	-1.7e-06	0.00002*	1.98e-06
	(1.15e-06)	(0.000012)	(7.66e-067)
AGE	0.0103***	-0.0747*	-0.0412
	(0.0031)	(0.0407)	(0.0283)
US	-0.7598***	4.8048**	2.1013
	(0.0677)	(2.1223)	(1.6293)
Type of Cargo Variables			
CRUDE			1.4999***
			(0.2260)
FUELOIL			0.8848***
			(0.2696)
DIESEL			0.1496
			(0.4135)
Operation Status			
CARGO			-0.0696
			(0.1951)
UNDERWAY			1.8808***
			(0.4569)
Constant	0.3069***	10.6039***	7.0434***
	(0.0784)	(2.7277)	(2.0297)
$\psi(w\hat{\gamma})$		-12.5212***	-7.0197**
		(4.2647)	(3.2204)
N	2263	784	784
Log Likelihood	-1178.2977		

*** significant at the 1% level.
** significant at the 5% level.
* significant at the 10% level.

Table 7: Probability of a Spill for Different Vessels
US flag vessels are in parenthesis

	10000 gross tons	32000 gross tons	100000 gross tons
5 years old	0.6336	0.6194	0.5747
	(0.3378)	(0.3243)	(0.2839)
15 years old	0.6716	0.6580	0.6146
	(0.3762)	(0.3622)	(0.3197)
25 years old	0.7079	0.6950	0.6534
	(0.4159)	(0.4014)	(0.3574)

Table 8: Probability of a Spill for Accident Types
15 year old vessel that weighs 32000 gross tons

	Foreign Flag	US Flag
Base Case [1]	0.6580	0.3622
GRNDING	0.0679	0.0122
COLLISION	0.1389	0.0325
WEATHER	0.6393	0.3434
IMPMAINT	0.6605	0.3647

[1] All dummy variables except for US are zero.

about 58 percent compared to about 66 percent for medium vessels and 67 percent for small vessels. If we think of a grounding or a collision of a certain severity, we would expect an older vessel to be damaged more since the hull material would be more corroded. Similarly, a large vessel would sustain less damage compared to a small vessel. Larger the damage is to the vessel, the greater would be the likelihood of a spill.

In Table 8 the effect of the accident type on the probability of spill is compared with the "Base Case" when the cause of the accident is neither of the four variables. These probabilities are for a 15 year old vessel that weighs 32000 gross tons. The probability that a grounding of a collision will result in a spill is very low, 7 percent for foreign flag vessels and 1.2 percent for US flag vessels. These probabilities are doubled for collision. These figures are interesting in that they show that most spills are not caused by what we conventionally think of vessel accidents, i.e. collisions and groundings, but are probably due to cargo operations.

We could not specifically control for this effect at this stage of the estimation due to data limitations. For accidents that result from bad weather or from improper maintenance, the probability of a spill is much larger, about 65 percent but these variables were not found to be significant.

The size of the spill is estimated with two sets of independent variables. The first set assumes that determinants of size of oil spills are the same as the determinants of the probability of spill conditional on an accident. The second set adds type of cargo variables and two operation status variables to the to the first set. The correction term is significant in both cases indicating the presence of a sample selection effect. Since its sign is negative spill size would be overestimated if the selection effect is not incorporated. This effect is stronger for accidents where the spill probability is low. Failing to account for the sample selection effect, given its significant negative sign, would greatly affect our estimates of spill size for those where the spill probability is low such as in groundings and collisions.

The grounding and collision variables have significant positive signs in both cases. The flag variable is significant at the 5 percent level with a positive sign, and the size and age variables are significant at the 10 percent level in the first model. Size has a positive coefficient while age has a negative coefficient.

Table 9 compares the effect of accident type on spill size for foreign flag and US flag vessels. A spill caused by a grounding is about 30000 gallons for foreign flag vessels, and 855 gallons for US flag vessels. Collision has a less dramatic effect on spill size, still increasing spill size by hundredfold compared to the base case. The effect of weather damage and improper maintenance is to double spill size but these variables are not found to be significant.

Table 9: Spill Size for Accident Types
15 year old vessel that weighs 32000 gross tons
Spill size is in gallons
(ψ_i are in parenthesis)

	Foreign Flag	US Flag
Base Case [1]	22.9873	7.1430
	(0.5581)	(1.0352)
GRNDING	29373.9633	855.6440
	(1.9315)	(2.5977)
COLLISION	1873.5230	73.3536
	(1.5937)	(2.2362)
WEATHER	23.1565	6.4801
	(0.5855)	(1.0710)
IMPMAINT	21.9800	6.9259
	(0.5544)	(1.0304)

[1] All dummy variables except for US are zero.

The significance of all vessel characteristics disappear with the addition of the new variables. Tankers carrying crude oil and fuel oil tend to have larger spills, as well as vessels that have an accident while underway. Table 10 compares the effect of accident type and the new variables on spill size for foreign flag and US flag vessels. The inclusion of the new variables significantly reduces the effect of grounding on spill size for foreign flag vessels but causes a slight increase for US flag vessels. Spill size due to collision increases for all vessels but disproportionately for US flag vessels. The effect of all other dummy variables on spill size can be considered modest. A crude oil spill is only 58 gallons larger on average for foreign flag vessels.

In light of these results, vessel characteristics are not important in determining the size of spills. The results strongly suggest that collision and groundings cause larger spills if they do cause a spill, but they are not likely to cause a spill. The clause in the Oil Pollution Act of 1990 regarding compulsory double hulls for tankers was largely aimed at preventing large

Table 10: Spill Size
15 year old vessel that weighs 32000 gross tons
(ψ_i are in parenthesis)

	Foreign Flag	US Flag
Base Case[1]	13.0770	3.7554
	(0.5581)	(1.0352)
GRNDING+UNDERWAY	12048.1182	917.7233
	(1.9315)	(2.5977)
COLLISION+UNDERWAY	2633.3576	236.7580
	(1.5937)	(2.2362)
WEATHER	10.4471	2.8291
	(0.5855)	(1.0710)
IMPMAINT	12.7113	3.6791
	(0.5544)	(1.0304)
CRUDE	58.6012	16.8289
FUELOIL	31.6790	9.0975
DIESEL	15.1872	4.3614
CARGOOPS	12.1978	3.5029
UNDERWAY	85.7688	24.6308

[1] All dummy variables except for US are zero.

spills and may not have a significant effect on oil pollution from tanker accidents on average. Information on double hulls is only available starting in 1992, so we could not specifically test for this effect. It is also interesting that the significance of the flag variable disappears with the addition of new variables. The flag variable has always been found to significantly reduce spill size in the literature. This might have been due to different traffic patterns for foreign flag and US flag tankers, rather than better regulations. The flag variable ceases to be significant due to the addition of cargo type variables supporting this claim. The results also show that the causality between larger tankers and larger spills as found in the literature disappears with the addition of information regarding the accident. Tanker size has never been regulated even though it has been widely believed that larger spills have a lot to do with larger vessels. Here this relationship is shown to be tenuous.

6 Conclusion

In this paper the determinants of spill size are estimated in a sample selection model utilizing detailed data on spills. The results show that vessel characteristics are not very informative in explaining spill size. Tanker size is found to have only a marginal effect on the probability of a spill and a dubious effect on spill size. US flag tankers and new tankers are found to have a lower probability of causing spills compared to foreign flag and old tankers, respectively. However, US flag tankers do not have smaller spills when type of cargo variables are included in the analysis. These results cast doubt on the widely held belief that US flag tankers have smaller spills because they are better regulated. It appears more probable that US flag vessel tankers have smaller spills due to differing traffic patterns, and not due to better regulations.

Spills caused by grounding or collision are found to be significantly larger than spills due to other causes, but the probability that there will be a spill due to grounding or collision is significantly lower than for other causes. Regulations that largely target spills due to grounding or collision should be evaluated in this light.

Crude oil spills and fuel oil spills are found to be larger on average. Crude oil is generally transported in large and ultra-large tankers that rarely cause spills. However, when they do get involved in such a serious accident that a spill occurs, the spill is likely to be large. The result for fuel oil spills is harder to explain. It is possible that due to the high consumption of fuel oil, it is transported in large tankers. We have tested to see if this result is driven by a major fuel oil spill in the sample and rejected it.

Appendix A
CASMAIN (1980-1991)
67954 Records

	Name	Sample Entry	Description
Casualty Case Number	mccase	MC85000589	Case Number assigned to each casualty
Vessel Identification Number	vin	L7368267	
Vessel Key	vkey	VN83941992	Computer generated vessel number for USCG purposes
Number of Vessels Damaged	numvsdam	VN83941992	
Date of Incident	case_date	04/10/91	
Day or Night	period_day	D	Day, if incident took place during the day etc.
Weather	weather	RN	Weather conditions at the time of the incident
Water	water	17PIBW	Body of water casualty ocurred in
Latitude	latitude	N 61 05.5	
Longitude	longitude	W 146 22.5	
Report Type	rep_type	CG2692	Type of report filed for the casualty
Total Damages	total_damages	25000.00	Total damages for casualty, including damages for all vessels if multiple vessels were involved
Investigating Office	unit	ANC	MSO Office Investigating Casualty
River Milepost	milepost		If casualty is on river
Entered By	enter_by	CPFL/CPFC	USCG employee recording the case
Wind Direction	wind_dir	NW	
Wind Speed	wind	050	
Visibility	visibility	010.0	
Number of Vessels Involved	inv_vsl	1	Number of vessels involved in the casualty
First Nature of Casualty	nature1	MATHST	This is what casualty is primarily classified as.
Second Nature of Casualty	nature2		The casualty can also be classified as "nature2".
Third Nature of Casualty	nature3		The casualty can also be classified as "nature3".
First Cause of Casualty	cause1	ADVWTH	First cause of nature1
Second Cause of Casualty	cause2		Second cause of nature1
Third Cause of Casualty	cause3		Third cause of nature1
Fourth Cause of Casualty	cause4		First cause of nature2
Fifth Cause of Casualty	cause5		Second cause of nature2
Sixth Cause of Casualty	cause6		First cause of nature3
Seventh Cause of Casualty	cause7		Second cause of nature3

CASMAIN (1980-1991)

67954 Records

	Name	Sample Entry	Description
Sea Conditions	sea_con	HVY	Sea conditions at the time of the casualty
Tow Configuration	config		
Name of Vessel	vname	FORT STEELE	
Flag of Vessel	flag	US	
Year Vessel was Built	yr_built	1971	
Type of Vessel	service	TNK	
How Seaworthiness was Affected?	abc	A	A if vessel was a total loss, B if seaworthiness was affected, C if seaworthiness was not affected.
How Vessel was being used	v_use	OIL	
Length of Vessel	length	811	
Size of Vessel	gr_tons	37784	In gross tons
Hull Material	hull	ST	
Type of Vessel Propulsion	prop	SG	
Horsepower	hp		Engine power
Hull Design	design	CONV	
Vessel Damage	vessel_damage	25000.00	Dollars
Value of Cargo Lost	cargo_damage	0.00	Dollars
Crew Death	crew_death	0	Number of Crew Deaths
Passenger Death	pass_death	0	Number of Passenger Deaths
Total Death	total_death	0	Number of Total Deaths
Crew Injury	crew_injury	0	Number of Crew Injuries
Passenger Injury	pass_injury	0	Number of Passengers Injuries
Total Injury	total_injury	0	Number of total injuries
State of Vessel	vsl_state	AU	Afloat, aground etc.
Person in Charge	person_ic	LDID	Person in charge of vessel movement
Vessel Society	society	ABS	
Operating Company	oper_co	TRINIDAD C	
Verification of Licensed Pilot	pilot	NONE	
Inspection Indicator	ind	Y	Y, N ,U
Certificate Issue Date	coi_date		Date Certificate of Inspection was issued
Issuing Office	imso	Y	MSO issuing Certificate of Inspection

Marine Pollution Substance File (1985-1991)

66684 Records

	Name	Sample Entry	Description
Pollution Case Number	mpcase	MP85000589	Case Number assigned to each pollution incident
Supplement ID	supplement_id	0001	Differentiates the vessels involved in a pollution incident when multiple vessels are involved
Substance Code	chris_code	OIL	USCG code for substance spilled
Potential Quantity	potential_qty	21000	Quantity the vessel was carrying
Amount spilled on land	out_of_water_spilled	2	
Amount recovered on land	out_of_water_qty_rec	2	Amount spilled on land that was recovered
Amount spilled in water	in_water_qty_spilled	2	
Amount recovered in water	in_water_qty_rec	1	Amount spilled on land that was recovered
Unit of Measurement	units_measure	GALLONS	Unit in which quantity spilled is measured
Substance Name	vrcase	OIL: CRUDE	Name of substance spilled

Pollution Vessel Supplement (1985-1991)

28669 Records

	Name	Sample Entry	Description
Pollution Case Number	mpcase	MP85000589	Case Number assigned to each pollution incident
Supplement ID	supplement_id	0001	Differentiates the vessels involved in a pollution incident when multiple vessels are involved
Name of Vessel	vname	FORT STEELE	
Vessel Identification Number	vin	L7368267	
Flag of Vessel	flag	UK	
Number of Pollutants	num_pollutants	1	Number of substances spilled; a tanker transporting products often carries several different products
Operation Status	p_operation	RECEIVING FUEL	Operation at the time of incident
Violation Case	vrcase	VR85004262	Violation report
Vessel Key	vkey	VN83941992	Computer generated vessel number for USCG purposes
Penalty Action	penalty_action	Y	Yes, if a penalty action was undertaken
Primary Cause of Pollution	primary_cause	EQUIPMENT FAILURE	
Secondary Cause of Pollution	secondary_cause	FLANGE FAILURE	
Primary Contributing Factor	contributing_factor_1	MATERIAL DEFECT	
Secondary Contributing Factor	contributing_factor_2	PERS. ERROR, NEC	
Type of Vessel	service	TANK SHIP	

Appendix B
Case Numbers

MC85000420	MC85003426	MC85005867	MC86000241	MC86002072	MC86003430	MC86005114	MC87000075	MC87001787
MC85000529	MC85003441	MC85005940	MC86000243	MC86002076	MC86003439	MC86005116	MC87000099	MC87001788
MC85000647	MC85003442	MC85005959	MC86000311	MC86002093	MC86003470	MC86005150	MC87000131	MC87001789
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MC85000739	MC85003515	MC85006041	MC86000338	MC86002144	MC86003516	MC86005249	MC87000236	MC87001827
MC85000774	MC85003566	MC85006104	MC86000361	MC86002259	MC86003567	MC86005259	MC87000254	MC87001854
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MC90000737	MC90002196	MC90004017	MC90006191	MC91000627	MC91001753	MC91003373	MC91006008	MP85002428
MC90000745	MC90002336	MC90004090	MC90006351	MC91000652	MC91001778	MC91003399	MC91006065	MP85002468
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