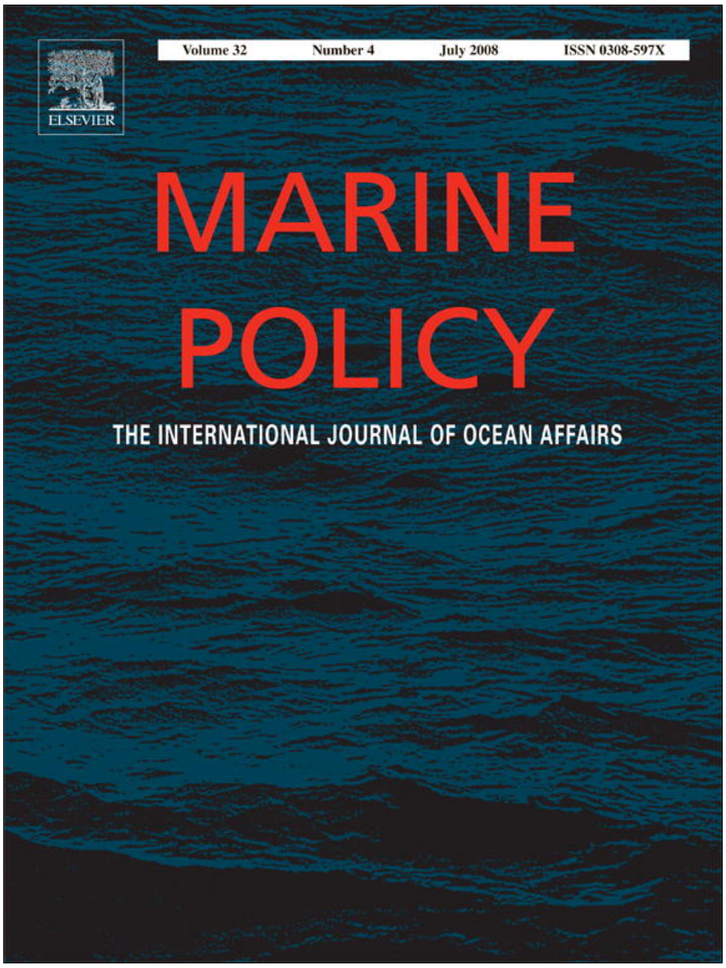

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OPA 90's impact at reducing oil spills

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Abstract

OPA 90 set out stringent requirements and liabilities for tankers operating in US national waters. OPA 90 was in response to the public concern caused by the grounding of the *Exxon Valdez* in 1989. It made ship owners responsible for the cost of pollution incidents and required all tank ships/barges operating in US waters have double hulls by 2015. We model factors influencing oil spills and test whether OPA 90 helped reduce the number of those spills. After accounting for causal factors, both increased liability and double hulls were statistically significant factors in reducing the number of spills.

Keywords: OPA 90; Oil spills; Modeling oil spills

1. Introduction

In March 1989, the tanker *Exxon Valdez* grounded in Prince William Sound spilling more than 11 million gallons of crude oil into Alaskan waters. This event bolstered public concern about the costs and risks of maritime oil transportation. This resulted in changes to tank vessel design and marine safety and environmental protection regulations. In August 1990, the US Congress passed the Oil Pollution Act of 1990 (OPA 90 or "the Act").

The Act mandated comprehensive oil pollution liability, compensation, prevention and response requirements. The Coast Guard promulgated over 30 final rules as a result of the Act. Most notable of these were rules for increased liability limits, contingency response plans, and double hull tank vessel requirements that attempted to focus industry on the risks and costs of shipping and oil pollution. The double hull requirements would require all tank ships and barges operating in US waters to have double hulls by 2015 as implemented by a phase-in schedule beginning in 1995.

In addition to the Act, the United States in November 1990 also proposed to the International Maritime Organization (IMO) similar world fleet requirements for double hull tank vessels. This eventually led the international community to endorse the goals of the Act by implementing international standards that required the phase-in of double hull vessels for most tanker trades by 2015 and additional operational and structural measures for existing double hull tankers.[2]

Since the adoption of the Act, there has been a reduction in the number and volume of large petroleum oil spills by tank ships and barges in US waters, see Fig. 1 (all spills) and Fig. 2 (volume of all spills in thousands of gallons). Reviewing the period since the Act, 1990–2004, the number and volume of petroleum oil spills by tank ships and barges maintained a downward trend with some years of variation [1].[3]

Available spill data since the early 1970s, when the Coast Guard began compiling national spill data, show that the number and volume of spills also declined in the period before the Act, see Fig. 3 (all spills) and Fig. 4 (volume of all spills in thousands of gallons). Reviewing the years before the Act, 1976–1990, we find that the number and

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[2] Included amendments to Regulations 13F and 13G of Annex I of The International Convention for the Prevention of Pollution from Ships, as originally adopted in 1973 and modified in 1978 (MARPOL 73/78). See National Academy of Sciences, 1998, for additional discussion of national and international double hull tanker legislation and requirements.

[3] Source: US Coast Guard; see the Oil Spill Compendium, http://www.uscg.mil/hq/g-m/nmc/response/stats/aa.htm.

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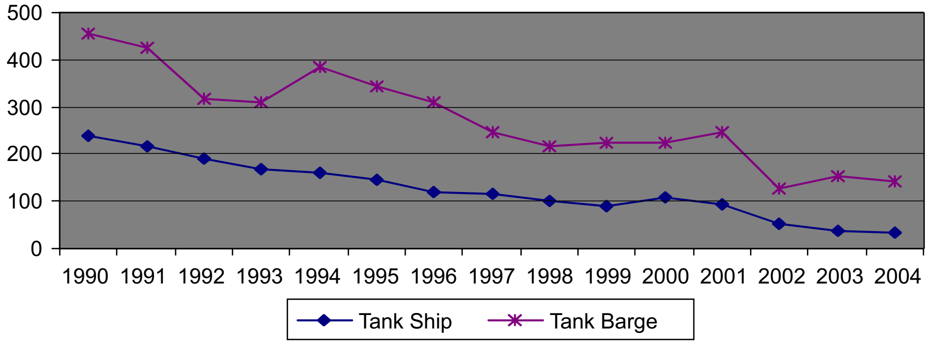

Fig. 1. Count of tank vessel spills, 1990–2004.

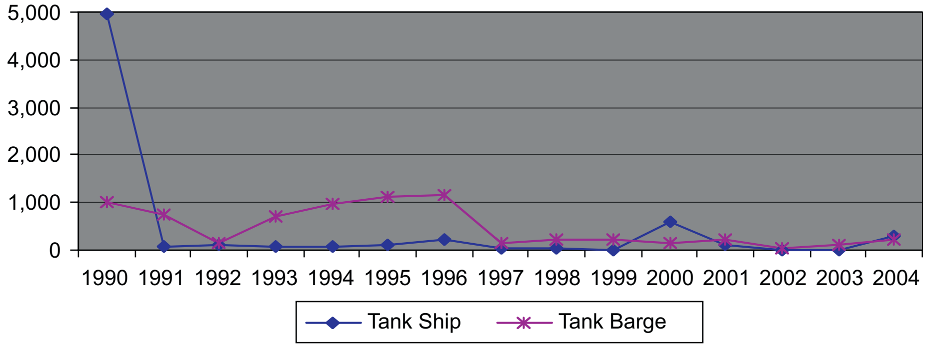

Fig. 2. Volume of tank vessel spills, 1990–2004 (1000 gal).

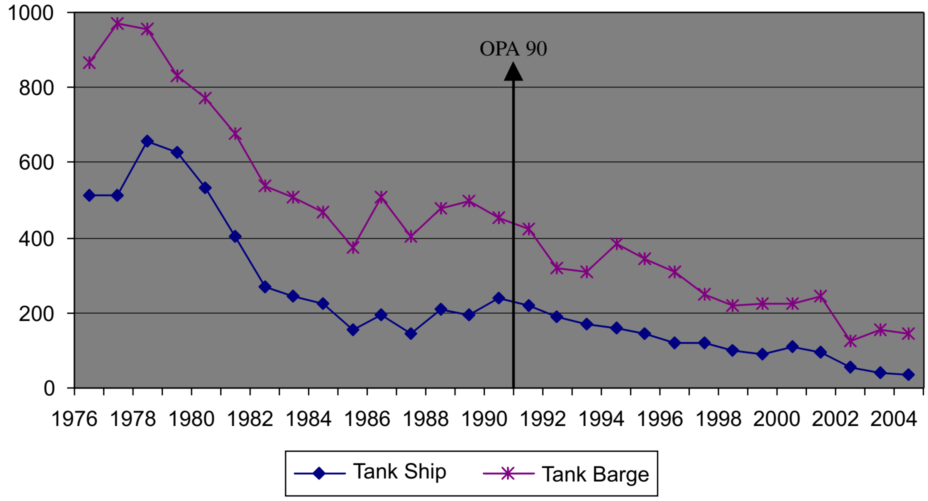

Fig. 3. Count of tank vessel spills, 1976–2004.

volume of oil spills generally maintained a downward trend with precipitous declines within some years, such as the early 1980s. Based on a non-statistical review of data for all years, 1976–2004, we cannot determine if or how the Act contributed to the overall trend of decreasing frequency and volume of spills.

This paper attempts to explore whether the passage of the Act was a statistically significant factor in explaining the reduction in the number of petroleum oil spills from tank vessels. We review current literature and research on the determinants of oil spills and the effectiveness of the Act. We then attempt to model factors that influence oil spills, based in part on findings in the literature, and test if the Act played a role in the reduction of large oil spills since its passage. In this research, we also consider various sources of historic industry data for measuring how commodity traffic, prices, vessel population, and vessel characteristics influence oil spills.

The organization of the paper is as follows. Section 2 provides a review of the pertinent literature and identifies

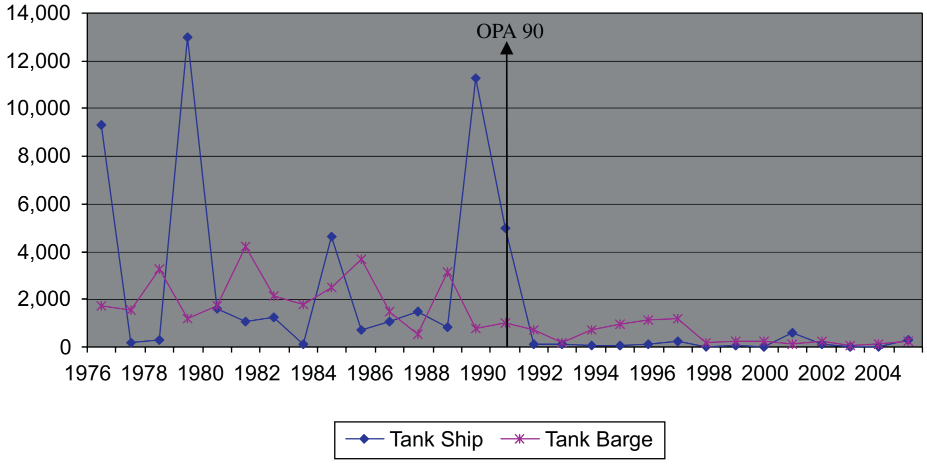

Fig. 4. Volume of tank vessel spills, 1976–2004 (1000 gal).

causal factors that will drive the econometric models. Section 3 that follows describes the methodology and identifies the models used. Section 4 provides a description of the data sources, and Section 5 discusses the results of the models and their implications. Section 6 concludes the paper.

2. Literature review

Many historical models of oil spills develop probabilistic estimates of oil spill occurrence. Frequently, researchers have modeled spill occurrence as a Poisson process [2–4]. In these models, a stochastic process $N(t)$ is a counting process if $N(t)$ represents the total number of events that have occurred up to time t. These models generally model spills as a function of oil handled, or similar variables such as volume landed or number of trips.

Sarin and Scherer [5] suggest that tanker accident spillage increases with tanker size. This, of course, is a function that larger tankers can handle more oil. Meade et al. [6] found that smaller tankers exhibit higher accident rates than larger tankers. However, most accidents do not result in spills and higher accident rates do not necessarily imply higher spill rates. They also found that the older tankers were not more prone to accidents than newer ones. Talley and Anderson [7,8] have modeled the determinants of accident oil spillage. In addition to investigating factors such as vessel size and age, they also investigated the price of oil and the price of shipbuilding and repair. The rationale for the latter two variables was that vessel owners would be more careful as the price of oil increased (more valuable cargo) and as the cost of repairs increased. Both factors tend to increase the cost of negligence. A complicating factor in modeling tanker oil spills is in the general inability of being able to monitor human error. In particular, Brooks [9] notes that the cause of the vast majority of tanker accidents is human error. Because of this, some have questioned the wisdom of mandating double hulls and that other approaches might be more cost-effective. Talley et al. [10] provide a summary of the pertinent literature.

Talley et al. [10] also investigated vessel accident oil spillage post-OPA 90 and found that tank barges have incurred greater oil spillage rates than non-oil cargo vessels but that tank ships have not incurred greater spill rates. However, the study does not address the general effectiveness of OPA 90. More recently, Kim [11] did a non-statistical review of OPA 90's effectiveness. Kim found that the number and volume of oil spills in US waters had fallen considerably since the passage of the Act. However, Kim's study does not control for changes in any explanatory variables.

This paper will model oil spills over time and investigate whether the passage of OPA 90 was a statistically significant factor in explaining the reduction in the number of oil spills. The paper will incorporate changes in determinants noted in the literature. Thus, the paper will control for any changes in other explanatory variables to isolate the effects of OPA 90. In doing so, the paper isolates the effects from the non-operational measures (increased liability, improved inspection and audits, etc.) and the operational measures related to double hulls.

3. Methods and model

3.1. Methods

The paper will use two approaches to investigate the impact of OPA 90 on reducing oil spills. The paper will model oil spills with the inclusion of a dummy variable starting with the effective year of OPA 90 (1991) and will model spills including a variable with the percentage of tank vessels that have double hulls. The paper will model the number of spills using two different dependant variables for spills. In the first case, the model includes spills of over 10,000 gal (about 238 barrels and the threshold amount for "larger spills" [8] while in the second case it includes all spills over 1000 gal (about 24 barrels). The latter quantity provides for a greater number of spills on which to establish the statistical relationship between the number of spills and the independent variables.

To model spills, we employ a count model. We can use these models when the dependent variable (y) takes integer values that represent the number of events that occur. In these cases, the dependent variable assumes discrete values, but is not a categorical value. Classic examples include fatalities in a city and the number of accidents on a pipeline. In the pipeline case, an explanatory variable could be a regulatory variable if we were interested in studying the effects of regulations on accidents. In such a case, a Poisson regression model would be appropriate [12]. This, of course, is similar to what we are trying to model in this paper.

With a Poisson model, the explanatory variables (Y_1, Y_2, …, Y_n) have independent Poisson distributions with parameters λ_1, λ_2, …, λ_n, respectively.

$$\text{Prob}(Y_i = r) = \exp(-\lambda_i)\left[\frac{(\lambda_i)^r}{\gamma_i}\right] \tag{1}$$

$$\ln \lambda_i = \beta_o + \sum \beta_j x_{ij} \tag{2}$$

With Poisson models, the variance is equal to the mean. This is not always true in actual data so it can limit the usefulness somewhat. The usefulness may also be limited if process does not have independent increments (i.e., independence of past events). This violation would occur if a spill event were not independent of a prior spill event; however, this does not appear to be the case with real-world spills.

Given the potential for over-dispersion, we generate two sets of results; one with the Poisson and one with a common alternative approach using a negative binomial specification.

$$\text{var}\left(\frac{y_i}{x_i}, \beta\right) = m(x_i, \beta)(1 + \eta^2 m(x_i, \beta)) \tag{3}$$

This approach is a way of adjusting the Poisson estimates by taking the amount of over-dispersion into account. In Eq. (3), η^2 is a measure of the extent that the conditional variance exceeds the conditional mean. To measure for over-dispersion, we use the Wooldridge test [13]. The test is a regression with the fitted values of y_i as the independent variable ($\hat{y}_i$) on e_{si}−1 (the squared standardized residuals−1).

$$e_{si} - 1 = \hat{y}_i \tag{4}$$

A significant t-statistic suggests over-dispersion and the value of the coefficient is an estimate of the necessary adjustment for it. We report whether the Wooldridge test is significant; however, for space conservation purposes, we report only the Poisson or the negative binomial estimates depending on whether the Wooldridge test was significant.

3.2. The model

We express the number of spills (SPILLS) as a function of petroleum handled (TRAFFIC), the number of tank vessels (TANK), average vessel size (SIZE), the price of petroleum (OILP) and the cost of repairing vessels (REPAIR).

$$\text{SPILLS} = f(\text{TRAFFIC}, \text{TANK}, \text{SIZE}, \text{OILP}, \text{REPAIR}) \tag{5}$$

The expected relationship between SPILLS and TRAFFIC is positive. As the amount of petroleum transported increases, the opportunity for a spill should increase all else held constant. Similarly, as more tankers transport petroleum we would expect that there are also more opportunities for a spill. Note that while TRAFFIC and TANK capture some similar characteristics, they also are different. For example, TANK does a good job of representing the potential threat (number of vessels) while TRAFFIC does a better job of capturing additional risk from characteristics such as increased trip frequency. Consequently, we use both variables.

The expected sign of SIZE is ex ante indeterminate. Smaller vessels may exhibit higher accident rates than larger vessels but do not have necessarily higher spill rates. At the same time, larger vessels have the potential for spilling greater quantities; the latter is of importance since we are only modeling relatively larger spills. The expected signs of OILP and REPAIR are negative. As the price of petroleum increases (more valuable cargo) and as the cost of repairs increases, vessel owners may be more careful since both factors tend to increase the cost of negligence.

To determine the effect of the Act, we add a dummy variable to the model. The variable, DM, is equal to 1 for years starting in 1991 and is 0 otherwise. OPA 90 included several measures that increased the cost of not being careful. This, of course, included the need for liability insurance of up to $10 million (or $1200 per gross ton, whichever is greater) and unlimited liability in the case of gross negligence (e.g., *Exxon Valdez*) [14]. If, as expected, OPA 90 has been primarily responsible for the drop in oil spills, we would expect the sign of DM to be negative. Similarly, we also run the model with a variable for the percentage of tankers that are double hulled (DH). As this percentage increases, we would expect the number of spills to drop. The expected sign for DH is also negative.

4. Data

We considered several data series and sources for this paper. Based on the methodology, our model requires several observations before and after the passage and implementation of Act to generate meaningful results. We researched and considered available annual and quarterly tank vessel and maritime transportation-related data for as many years as possible.[4]

We found limited data for most variables that we specified for original inclusion in our model. Based on data availability, we adjusted our model and did not include some variables that we would have originally wanted specified for the model (e.g., we did not include tank vessel age).[5] We also used alternate data sources as substitutes for some variables for which data were not available.[6]

In addition, we had incomplete data available on tank barge population, shipments, and vessel characteristics. We discovered this to be particularly challenging for tank barges operating coastwise (non-oceangoing), inland or on the Great Lakes. We found that complete annual data for these tank barges are not available before 1990.

For this paper, we used data for years 1976–2004. We reviewed available data and collected actual or substitute data for the number of spills (SPILLS), petroleum handled (TRAFFIC), the number of tank vessels (TANK), the percent of double hull tankers (DH), average tank vessel size (SIZE), the price of petroleum (OILP), and the cost of repairing vessels (REPAIR).

We used aggregate data from the US Coast Guard's Oil Spill Compendium for the annual number of petroleum spills in US waters. We used only in-water spills by US or foreign flag tank ships and barges that involved crude or refined petroleum products.[7] We additionally filtered the data for annual counts of tank ship and barge spills greater than 1000 gal (SPILLSB) and 10,000 gal (SPILLS) as a measurement of the count of spills by increasing spill volume.[8]

For data involving petroleum handled (TRAFFIC), we obtained annual waterborne commerce traffic and commodity data from the US Army Corps [15].[9] We used summary foreign and domestic traffic data for petroleum and petroleum products converted to gallons.[10] We did not attempt to disaggregate the petroleum commodity data in further detail past the four-digit commodity codes used by the Army Corps.[11] The annual traffic data that we use for this paper also does not distinguish between tank ship and barge vessel type or link the traffic to specific vessels or vessel deliveries.[12]

We used annual world-fleet-data series from Clarkson Research Studies for the number of tankers (TANK), the percent of double hull tankers (DH), and the average size or dead weight tonnage (SIZE) [16].[13] This data consists of world fleet tanker (i.e., tank ship) population and characteristics data and does not include tank barges. As mentioned before, we reviewed several sources and found limited availability of complete US and foreign flag tank vessel for US waters spanning over 30 years. For this paper, we used world fleet tanker data as a substitute for tank vessel population, percent double hull, and average size.

In our model, we also included a variable for the price of petroleum (OILP) and the cost of repairing vessels (REPAIR). For the price of oil, we used the adjusted (real) Imported Crude Oil Refiner Acquisition Cost (RAC) data series published by the US Energy Information Administration (EIA) [17].[14] This series represents the cost of imported crude oil to refiners. We used these data as a substitute for the price of petroleum because it includes transportation costs and other associated fees that may reflect costs associated with waterborne commerce in petroleum. Based on recommendations from the EIA, we used the imported data series because it more accurately reflects world prices than the alternate domestic or composite RAC series that can be distorted by domestic production.

We also included the variable for the cost of repairing vessels (REPAIR) as a measure of the cost to vessel owners of negligence. We used the Ship Building and Repair Producer Price Index data from Bureau of Labor Statistics

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[4] We created a quarterly data by using the same annual data series available in quarters, or if quarterly data were not available, we transformed the annual series into quarterly data based on the annual change between years adjusted over four quarters.

[5] Complete age information for all tank ships and barges operating in US waters were not available on an annual basis before 1997.

[6] We did find other propriety data sources that would potentially have available data for a cost that more closely matches the variables that we originally specified and intended to use in our model. For this paper, we used publicly available data or off-the-shelf proprietary data previously obtained by the Coast Guard.

[7] For this paper, we originally considered modeling spills of crude petroleum and all petroleum products for tank ships and barges separately. However, distinct tank ship and barge data for petroleum traffic and other data are not available for all years in our period of analysis. We used combined (total) tank ship and barge data series for spills and petroleum handled (traffic) to generate the results discussed in this paper.

[8] We attempted to look at large crude petroleum spills for tank ships only; however, we discovered that some years had no large crude petroleum spills for tank ships.

[9] We acquired recent summary traffic data for the past few years at http://www.iwr.usace.army.mil/ndc/. We obtained archived summary traffic data from data discs and reports published by US Army Corps of Engineers.

[10] The US Army Corps of Engineers publishes the total volume of petroleum traffic in short tons.

[11] The collection and detail for disaggregated commodity categories of petroleum traffic data changed over the series for years 1976–2004. We used the aggregated totals at the four-digit commodity level.

[12] Based on discussions with the US Army Corps of Engineers, linkages between historical commodity traffic and vessel data are not complete before 1994 and are not available before 1990.

[13] Source: 2007 Clarkson Research Services; The Tanker Register (2000, 2003, and 2005 editions), Clarkson Research Studies. Data for double hull vessels was available beginning in 1986 from the Clarkson Series ID #57292, "Total Double Hull (10k + DWT) Tanker Fleet Development Number." For the purposes of this paper, we assume the percent of the number of double hull tank ships before 1986 was effectively 'null' or zero. The Act required double hull implementation schedules beginning in 1995.

[14] Source: 2005 Annual Energy Review, Energy Information Administration, http://www.eia.doe.gov/emeu/aer/petro.html. The Refiner Acquisition Cost (RAC) data series is in real or chained (2000) dollars per barrel, calculated by using the Gross Domestic Product Implicit Price Deflator.

(BLS). However, the series was only available from 1986 through 2004.[15]

5. Results

We first run the models for the years before OPA 90 (1976–1990). We first do this with annual data and we next do so with quarterly data. We use quarterly data to have a more robust number of observations. Once we have estimated these models, we estimate the model over the full sample period of 1976 through 2004 to determine the impact of the OPA 90 variables. Although the pre-OPA 90 annual models suffer from having too few observations, the results are very important for comparison purposes to the annual models over the whole sample period (1976–2004). They will also be important later in the paper for comparing the actual number of spills to the expected number of spills had Congress never passed the OPA 90 legislation.

With the annual data and larger spills as the dependent variable, the coefficients for OILP and TANK were significant and had the correct sign. This would imply that fewer spills occurred when petrol prices were relatively higher and that spills were an increasing function of the number of vessels that were active. The coefficient for SIZE was positive and significant. This may be an indication that higher accident rates for smaller vessels do not translate into higher spill rates, or may be a function of the types of routes that larger vessels take. Conversely, the results for SIZE may just be reflecting that relatively insignificant spills on vessels with greater capacity are likelier to cross the gallon thresholds used for the dependent variable. With the model including smaller spills as the dependent variable, the model was more significant with .76 as the R^2 (as opposed to .56 with the larger spills). With this model, both TRAFFIC and TANK were positive and significant indicating that spills were an increasing function of active vessels and overall traffic.

Both models suffer from having too few observations. Consequently, we also run these models with quarterly data. For larger spills, the coefficients for OILP and SIZE were significant. As before with the annual data, OILP was negative and SIZE was positive. For the model including smaller spills, both TANK and SIZE were positive and significant and OILP was negative and (barely) significant at a 90% level of confidence. Taken as a whole, these models indicate that before OPA 90, spills were a positive function of vessel traffic (fleet and/or total petroleum traffic), vessel size, and a negative function of the price of petrol. Table 1 presents the results for the pre-OPA 90 models.

Table 1
Pre-OPA 90 models (1976–1990)

Model	Independent variables	Coefficient	*t*-statistic	R^2	*N*
SPILLS[a]	Constant	−1.114	−1.06	0.56	15
	TRAFFIC	3.5E−12	1.08		
	OILP	−0.017	−2.61***		
	TANK	0.0004	1.98**		
	SIZE	2.88E−05	2.21**		
SPILLSB	Constant	−0.335	−0.39	0.76	15
	TRAFFIC	3.63E−12	1.78*		
	OILP	−0.005	−0.83		
	TANK	0.001	4.41*		
	SIZE	1.54E−05	1.37		
SPILLS	Constant	−1.947	−1.10	0.13	60
	TRAFFIC	−1.36E−11	−0.88		
	OILP	−0.021	−1.89*		
	TANK	0.0005	1.42		
	SIZE	3.92E−05	1.75*		
SPILLSB[a]	Constant	−1.824	−2.08**	0.40	60
	TRAFFIC	1.74E−12	0.22		
	OILP	−0.009	−1.66*		
	TANK	0.001	4.90***		
	SIZE	2.40E−05	2.06**		

[a] Wooldridge test is significant.
*Significant at 90% level of confidence.
**Significant at 95% level of confidence.
***Significant at 99% level of confidence.

For the whole sample period, we are interested to see if the relationships between spills and the causal factors that existed pre-OPA 90 are still the same. We are also interested to determine if after taking these factors into account the decrease in the number of spills was due to the Act. Of greater importance, is whether the double hulling of tankers was marginally effective at reducing the number of spills after taking into account the other OPA 90 provisions that preceded it? Consequently, this leads to the following two testable hypotheses.

H1. : The OPA 90 provisions effective January 1991 did not have an effect on reducing spills.

H2. : The OPA 90 provisions requiring double hulls did not have an effect on reducing spills.

H1 is simply a test of whether the DM dummy variable is negative and significant or not. If it is not, then we accept the null hypothesis. Similarly, H2 is simply a test as to whether the DH variable is negative and significant. Since the double hull requirement for existing vessels was not effective until 1996 (new builds deliveries starting earlier), H2 is also a test to determine whether the marginal effect of double hulling (over and above the OPA 90 provisions that preceded it) was significant.

Table 2 presents the results for all the models over the full estimation period. As can be seen with the annual data, both DM and DH were negative and highly significant. This was true for both spill size models. For the model with larger spills as the dependent variable, the coefficient for TRAFFIC was also significant and was positive. For the

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[15] Source: 1986–2004 Ship Building and Repair Producer Price Index (NAICS Code 336611; Series #PCU336611336611), Bureau of Labor Statistics (BLS).

Table 2
Full period models pre- and post-OPA 90 (1976–2004)

Model	Independent variables	Coefficient	*t*-statistic	R^2	*N*
SPILLS[a]	Constant	1.024	0.74	0.84	29
	TRAFFIC	7.15E−12	1.98**		
	OILP	−0.0014	−0.13		
	TANK	4.71E−05	0.21		
	SIZE	−8.33E−08	−0.005		
	DM	−0.993	−4.34***		
	DH	−0.019	−2.24**		
SPILLSB	Constant	1.154	1.53	0.93	29
	TRAFFIC	7.38E−12	2.94***		
	OILP	0.002	0.26		
	TANK	0.0003	2.15**		
	SIZE	−6.59E−07	−0.06		
	DM	−0.593	−4.08***		
	DH	−0.040	−7.35***		
SPILLS	Constant	−2.255	−1.37	0.38	103
	TRAFFIC	−1.93E−11	−1.36		
	OILP	−0.025	−2.63***		
	TANK	0.0006	1.84*		
	SIZE	4.42E−05	2.23**		
	DM	−1.152	−5.53***		
	DH	0.507	0.75		
SPILLSB[a]	Constant	−1.220	−1.40	0.72	114
	TRAFFIC	−2.81E−13	0.03		
	OILP	−0.011	−2.08**		
	TANK	0.0007	4.36***		
	SIZE	2.33E−05	2.01**		
	DM	−0.728	−5.15***		
	DH	−2.683	−5.44***		

[a] Wooldridge test is significant.
*Significant at 90% level of confidence.
**Significant at 95% level of confidence.
***Significant at 99% level of confidence.

model including smaller spills, the coefficients for TRAFFIC and TANK were also positive and significant (as before with the pre-OPA 90 model). As before, this would imply that that spills were an increasing function of the number of vessels that were active and the petroleum handled by these vessels (for example, frequency of trips). Therefore, causal factors influencing the number of spills were still present. However, as is seen anecdotally with the data, the number of spills declined substantially starting in 1991. The significance of the DM variable clearly picks up this fact. The significance of the DH variable picks up the fact that the marginal effect of double hulling new vessels further reduced the number of spills. Based on the annual models, we can reject the null hypotheses that OPA 90 provisions did not reduce the number of spills.

As with the pre-OPA 90 models, we also run these models using quarterly data. As with the pre-OPA 90 models, spills continue to be an increasing function of active vessels and size, and a decreasing function of the price of petrol. For the model with larger spills as the dependent variable, TANK is now significant. For this model, the OPA 90 dummy is negative and significant but the double hull variable is not. For the model that includes smaller spills as the dependent variable, both the DM and the DH variables are negative and highly significant. Based on the quarterly data, we can also reject the null for H1 but the results are indeterminate for H2. What is also of interest with the quarterly models is that SIZE is a positive and a significant factor across all models but is not with the annual data. While interesting, these questions are outside of the scope of the study.[16]

For both the annual and quarterly models, the primary variable of interest, DM, is negative and highly significant. These results are very robust with respect to modeling technique. The use of categorical variable such as DM avoids imposing any specific relationship between DM and spills. While there are strong reasons for using the Poisson framework (see Section 3.1), the results for DM are robust to other methods. For example, the results for DM are still negative and significant when running an ordinary least squares model (in logs). The interpretation of the DM coefficient is also worth noting. We need to convert the coefficient value to percentage terms such that the interpretation is percent fewer spills in a post-OPA 90 year (or quarter). For example, using the annual model for larger spills, the coefficient for DM is equal to -0.993. This becomes -0.6295 $(-0.6295 = e^{-0.993}-1)$, which implies about 63% fewer spills in a post-OPA 90 year due to the Act's non-operational measures alone.

The results for these models, in particular, the annual models, have high predictive power in explaining the number of spills post-OPA 90 (1991–2004). Figs. 5 and 6 demonstrate how close the expected number of spills from the model tracks the actual number of spills for larger and smaller spills, respectively. Of perhaps greater interest is the difference between the actual number spills post-OPA 90 and the number of expected spills had OPA 90 never occurred (based on pre-OPA 90 models shown in Table 1). For example, with larger oil spills there would have been an expected 26 spills in 2004 as opposed to the actual number of five spills. Including smaller spills, there would have been an expected 94 spills as opposed to the actual seven spills. Figs. 5 and 6 also demonstrate this. In these figures, the actual number of spills are "Spills", the "Predicted No OPA 90" line represents the expected number of spills based on the pre-OPA 90 models, and the "Predicted Post OPA 90" line represents the number of spills based on the full period models shown in Table 2.

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[16] We also ran the models without the SIZE variable and the results and overall significance do not change much for the models using annual data. For the models using quarterly data, while the overall significance did not substantially change the coefficient for OILP was no longer significant. We do not separately report these results for space conservation purposes. We also ran the models with the REPAIR variable. As noted in the data section, data for this variable are only available from 1986 onwards. We do not separately report the results since the variable is not at all significant and the models are from 1986 to 2004 as opposed to these that are from 1976 to 2004.

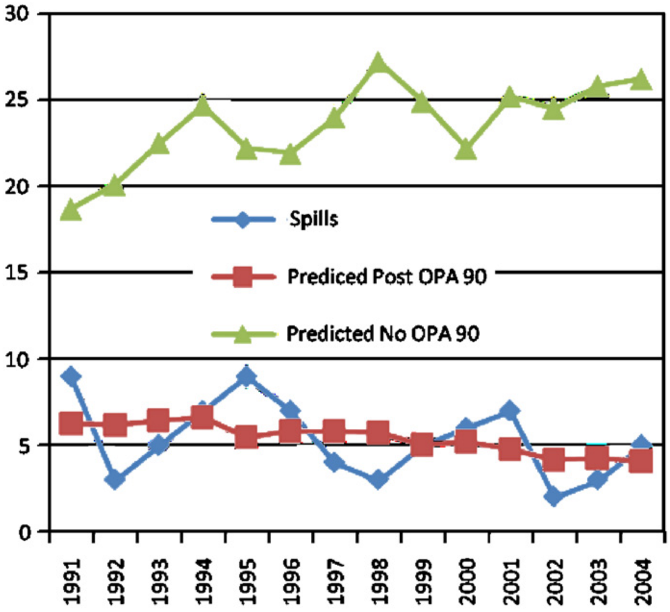

Fig. 5. Spills > 10,000 gal.

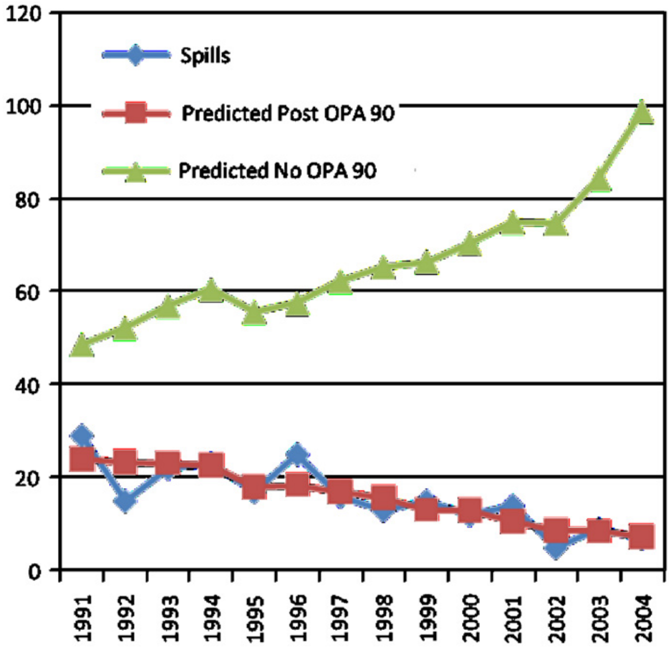

Fig. 6. Spills > 1000 gal.

6. Conclusion

This paper summarized research modeling the causal factors causing the number of spills and the effectiveness of the OPA 90 Act in reducing spills. We found, consistent with the literature, that spills are an increasing function of vessel traffic and amount of petroleum handled and a negative function of the price of petrol. These relationships were true both before OPA 90 and for the whole sample period from 1976 to 2004. We found that after controlling for these causal factors that OPA 90 was the most significant determinant in explaining spills. We found that the non-operational measures (increased liability, improved inspection and audits, etc.) that preceded operational measures related to double hulls were highly significant on their own. We also found that operational measures such as requiring double hulls on new builds and the phase-out schedule on existing vessels were also effective in reducing spills over and above the other measures that preceded them. We also estimated that had OPA 90 never occurred, spills would be substantially higher today than they were in 1990. Thus, the real reduction in spills (predicted "No OPA 90" minus actual spills) is even higher than the realized reduction from pre-OPA 90 levels. This is particularly so when we include relatively smaller spills. In this case, the expected number of spills (had there not been OPA 90) would have been over 80% higher than in 1990.

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