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ESTIMATION AND FORECAST OF OIL SPILL ACCIDENTS IN U.S. WATERS USING TRANSFER FUNCTION APPROACH*

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ABSTRACT

The environmental damages caused by oil spills and the costs to society of remedying such damages have raised the level of awareness of such pollution and the necessity to reduce their occurrences. As with the case with most accidents, it is very difficult to predict an oil spill event. However, with adequate data, this study has demonstrated that it is possible to generate a reasonable estimate of the aggregate number of future levels of oil spill incidents. An empirical model of the relationship between oil consumption and oil spill was developed using the familiar ARIMA framework. The results show that this type of model is useful in generating plausible estimate of levels of incidents and thus aid in the estimation of potential cleanup costs. The study estimates that annual average total cleanup up cost up to the year 2005 could be as low as $14 million and as high as $958 million in 1997 dollars.

1. INTRODUCTION

The relationship between energy consumption and economic growth has long been recognized. Concomitant to this established energy-development relationship, however, is the unavoidable environmental consequence of increasing energy consumption in most economies. Many of the energy-related environmental problems arise from fossil fuels production, processing, distribution, and use. Oil and gas consumption is the major component of fossil fuel consumed in most industrialized economies. A natural resource such as oil and gas are

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location specific and thus must be transported for processing and use across location, countries, or even continents. As the growth rate in oil consumption rises worldwide, it is not inconceivable to expect the risk and number of accidental oil spills to rise. Pollution arising from oil spill accidents is thus a major concern around the world. Here an "oil spill" connotes a discrete event in which oil is discharged by accident, neglect, or willful intent over a relatively short time [1]. Oil itself is defined as petroleum and its associated derivatives, but does not include liquefied natural gas or petroleum gas nor benzene, toluene, ethylene, and xylene.

Oil spill accidents are frequent occurrences in U.S. waters. In 2000, over 8,000 oil spill accidents involving more than 1.4 million gallons of oil occurred in diverse sources such as pipelines, tankers and other vessels, storage tanks, production rigs, and barges [2]. Although the Exxon Valdez spill of nearly 11 million gallons of crude oil off the coast of Alaska in 1989 marked a turning point in oil spill history and oil transportation policy, thousands of relatively smaller and less visible incidents are common occurrences. The estimated cleanup costs associated with the spill was estimated to fall between $1 billion to $2 billion. The total cost of the spill reached 13 billion in 1999 dollars [3]. The Valdez incident sparked the U.S. Congress to enact the Oil Pollution Act of 1990 (OPA 90) that, among other things, provided strict rules and regulations including an increased financial burden on polluters. Hence, the continued interest in the occurrence and environmental implications of these incidents worldwide.

The number of accidents and the volume of oil spilled are important considerations for environmental management purposes. While the importance of the magnitude of oil spilled is always a focus, the numbers of such incidents occurring over time are equally important for several reasons. First, in the monitoring and evaluation of spill prevention strategies and response readiness, the total number of incidents, especially in different size categories, is likely to be more useful information than the total volume spilled. Second, an estimate of the potential number of future incidents may be more significant in practical terms than predicting the occurrence of specific oil spill accidents and the associated spilled volume. This is because the distributions of spill incidents across different size categories are fairly similar from year to year. For example, about 87% of all spill incidents result in not more than 100 gallons of oil spilled, visible but relatively rare incidents such as the those resulting in spillage of 10,000 gallons or more are responsible for an average of about 90% of the total oil spilled in U.S. waters. Third, given the fairly stable distribution of such accidents over time, a fairly simple model providing reliable estimates of future levels of spill accidents allows for proper planning of remediation efforts and the potential cleanup costs [4]. Finally, an important policy assessment question is to what extent has OPA 90 or other regulations and rules been effective in curtailing both the number of accidents and the magnitude of oil spills?

Previous studies in the oil spill literature have been dominated by engineering, biological, and chemical analysis because the focus of the government has largely been on oil spill cleanup and abatement, as indicated by a review of the Louisiana Applied Oil Spill Research and Development Program database (Selected Abstracts and Bibliography of International Oil Spill Research—http://www.osradp.lsu.edu/), which comprises abstracts of over 4000 articles on oil spill research. Social and economic studies of oil spill events have been focused on estimating or assessing the risks of spill accidents [e.g., 5-7], or the value of damage caused [e.g., 8-10]. A few other studies have focused on evaluating the factors determining the occurrence and/or size of oil spill incidents from different sources and locations [11-14]. However, predicting any form of accident is always a daunting task because of the myriad of influential factors that underpin such events. In particular, oil spill accidents are notoriously difficult to predict; the probability of a spill occurring depends on several factors including location, weather conditions, mode of transportation, source, or even monitoring and enforcement quality, and so forth. Data on these variables are rarely collected on a consistent basis.

The objective of this article is to estimate and forecast the levels of accidental spills in U.S. waters using transfer function analysis in the tradition of Box-Jenkins ARIMA [15]. In addition, estimates of potential cleanup costs of future spill accidents are provided.

The remainder of this article is organized as follows: section II presents the econometric model, section III describes the data, section IV provides the empirical results and analysis, and section V presents the summary and conclusions.

II. ECONOMETRIC MODEL

Transfer function ARIMA models are powerful time series models that have been used to estimate and forecast variables in a wide variety of applications. Recent applications include Liu [16], Enders et al. [17], Trivez [18], and Fullerton and Tinajero [19]. The general formulation of an ARIMA model may be represented as follows:

$$Y_t = c + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + ... + \Phi_p Y_{t-p} + \varepsilon_t + \Phi_1 \varepsilon_{t-1} + \Phi_2 \varepsilon_{t-2} + ... + \Theta_q \varepsilon_{t-q}, \quad (1)$$

or, using lag operators:

$$(1 - \Phi_1 L - \Phi_2 L^2 - ... - \Phi_p L^p) Y_t = c + (1 + \Theta_1 L + \Theta_2 L^2 + ... + \Theta_p L^p) \varepsilon_t \quad (2)$$

where Y_t is the modeled series, Φ_i are the coefficients in the lag operator, L, c is a constant, and ε_t, the error term.

Given that the roots of the AR polynomial in (2) lie outside the unit circle, both sides of (2) can be represented as:

$$Y_t = \mu + \Psi(L)\varepsilon_t \quad (3)$$

where

$$\Psi(L) = \frac{(1 + \Theta_1 L + \Phi_2 L^2 + \ldots + \Phi_q L^q)}{(1 - \Phi_1 L - \Phi_2 L^2 - \ldots - \Phi_p L^p)} \tag{4}$$

$$\sum_{j=0}^{\infty} |\Psi j| < \infty$$

$$\mu = c / (1 - \Phi_1 - \Phi_2 - \ldots - \Phi_p).$$

The numerator and denominator terms in (4) represent MA and AR, respectively; and μ is the mean of the series, Y_t. In a Box-Jenkins formulation, a parsimonious representation of a univariate real-time series is preferred. A key assumption underlying (1) is that the series, Y_t is stationary. Otherwise, the difference, $\Delta^d Y_t$, must be taken to achieve stationarity implying Y_t is integrated of order d.

A transfer function model is an extension of ARIMA model with one or more exogenous variables serving as predictor(s) or *leading indicator*(s) of the response series, T_t. That is, the predictor variable's contemporaneous and past observations can be used to predict the future values of the series, Y_t. The exogenous variable(s) is (are) a stochastic process not constrained to have a particular deterministic path.

Consider a single variable transfer function, Z_t that is known for certain at time t. Assume Y_t is generated by an ARIMA (p, d, q) process as in (1), a transfer function model of the process may be formulated as

$$Y_t = v(B) Z_t + N_t \tag{5}$$

where

$$N_t = \frac{\Theta(B)}{\Phi(B)_t} \varepsilon_t \tag{6}$$

defines the "noise" aspect of the model, ε_t is a random shock, and v(B) is a polynomial which may be expressed in a rational form such that

$$v(B) = \frac{\omega(B)}{\delta(B)} B^k, \tag{7}$$

where

$$\omega(B) = \omega_0 - \omega_1 B - \ldots - \omega_s B^m,$$

$$\delta(B) = 1 - \delta_1 B - \ldots - \delta_r B^r,$$

and the "delay" in the effect or "dead time" for the transfer variable Z_t is defined by k. In this study, the response series Y_t, is the number of oil spill accidents and the input series Z_t, is the level of oil consumption. Note that in ARIMA notation, B is used to denote a "backshift operator" such that $B^i N_t = N_{t-i}$.

A crucial assumption in Equation (5) is that there is no feedback effect from Y_t to Z_t. Absence of a feedback implies that there is no simultaneity in the model; otherwise a transfer function is inappropriate. A test for simultaneity in Equation (5) can be accomplished using Granger-causality tests (a variable A is said to Granger cause B if a knowledge of A helps in improving the forecasting performance or prediction of B's path). Therefore, a plausible transfer model of oil spill accidents and oil consumption should indicate only a unidirectional causality from oil consumption to oil spill accidents and not in the opposite direction.

III. DATA SOURCES AND DESCRIPTION

The monthly spills data used in this study was obtained from the U.S. Coast Guard's Marine Safety Management System (USCG-MSMS) comprehensive database on spill accidents in U.S. Waters [2]. The database documents discharges reported to the Coast Guard by responsible parties, by other private parties, government agencies, or as discovered and reported by Coast Guard personnel. Included in the database are all reported discharges into U.S. navigable waters, including territorial waters (extending three miles to the coastline), tributaries, the contiguous zone (extending from three to twelve miles to the coastline), onto shorelines, or into water that threatens the marine environment of the United States. The USCG-MSMS is actually a combination of three database systems: the Pollution Incident Reporting System (1973-1985), the Marine Safety Information System (1985-1991), and the Marine Investigation Module (1991-present).

The data include the monthly number and quantity of spills from 1969 to 2000. According to the Coast Guard, the pre-1973 data has limited statistical integrity; so the analysis here is limited to the data from 1973 to 2000. A number of validation checks are usually run to test and verify data integrity. The data is frequently screened for gross errors or omissions, and corrections are made where necessary.

The data on oil consumption in the United States from 1973 to 2000 was obtained from the U.S. Energy Information Administration (EIA). This data is published in several issues of the EIA's Petroleum Supply Monthly and measured in thousand barrels per day.

Figures 1 and 2 present plots of the number of oil spill incidents and oil consumption levels in the United States between 1973 and 2000. As these graphs clearly show, both plots indicate distinct patterns of upward and downward swings. Up to 1980, the trends are generally upward. Then, a period of downward movements followed until the mid 1980s. While oil consumption has generally trended upward since 1985, oil spill incidents appear to have stabilized since 1993, although at a much higher levels than the early to mid 1980s. The trends in oil consumption clearly follow the trend in real oil prices over this period.

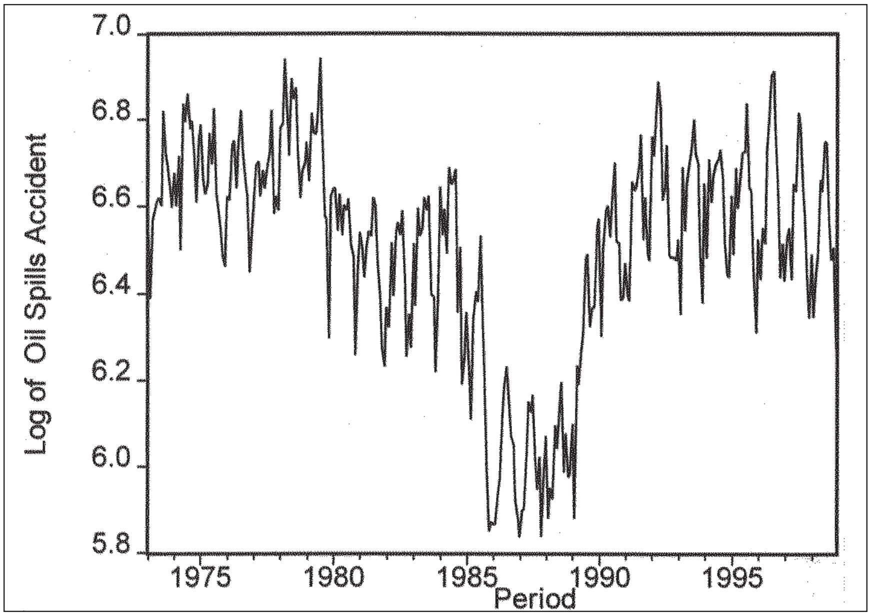

Figure 1. Oil spill accidents in U.S. waters, 1973-2000.

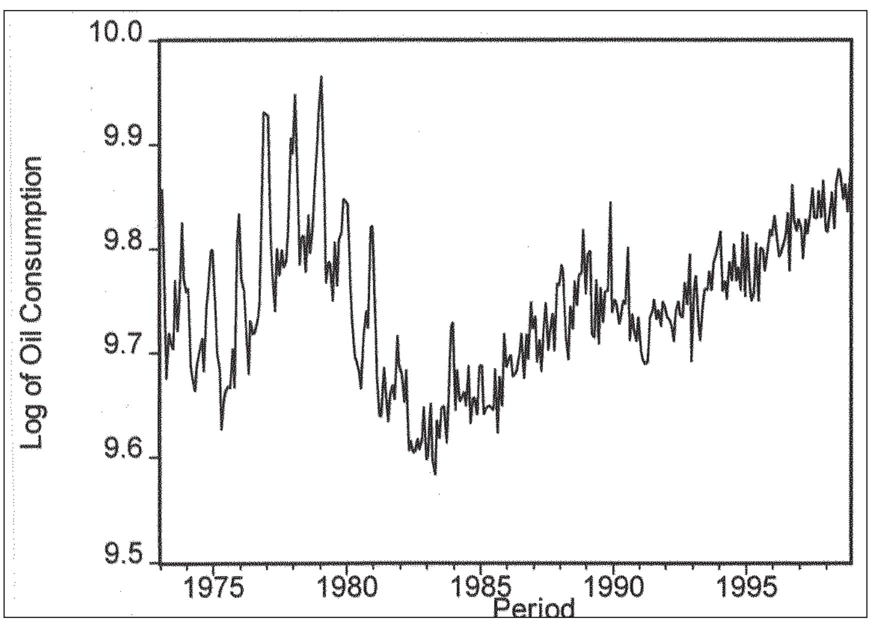

Figure 2. U.S. oil consumption per day, 1973-2000.

Although the trends in spill incidents are not entirely due to oil consumption, it has generally followed a similar pattern to oil consumption, more so, until the mid 1990s. The slight break in the upward trend in spill accidents since 1993 appears to be as a result of OPA 90 and other regulatory regimes in most of the states. It appears that spill incidents follow oil consumption movement albeit, with some lags.

Figures 3 and 4 depict the average distribution of spill incidents over the period of the analysis. Contrary to widespread perception in the popular media, only a few incident results in more than 1,000 gallons, and incidents such as the Exxon Valdez (greater than a million gallons) are very rare occurrences (Figure 3). Most spill incidents occur in rivers and canals (28%), followed by bays and sounds (21%) and the Gulf of Mexico (14.5%) as shown in Figure 4. Although not shown here, our analysis indicate that by location of occurrence, spill accidents occurring in internal waters accounts for about 50% and about a quarter of the incidents in coastal waters. Furthermore, in terms of distribution of incidents by source, vessels, besides tanks and barges and facilities (i.e., industrial, air transport, railway, and storage) dominate; vessels accounts for about 32% and facilities about 24%. Obviously, a major impetus for oil spill incidents is the transportation of crude and refined petroleum across the U.S. landscape.

IV. EMPIRICAL RESULTS AND ANALYSIS

The usual Box-Jenkins ARIMA procedure involves three stages of *identification, estimation, and diagnostic.* At the identification stage, visual inspection of the plot of the series, its autocorrelation function (ACF) and partial autocorrelation function (PACF) are examined to check for trend, structural change, and most importantly, stationarity or otherwise of the data generating process. If the series is not stationary then it must be appropriately transformed, usually by differencing, to obtain a stationary process.

An examination of both series shows the monthly number of oil spill incidents and volume of oil consumed are not stationary. Because both series appear to be non-stationary, we employ the general form of the augmented Dickey-Fuller (ADF) test, which involves regressing each series on constant, own lags, and a time-trend.[1] The results are shown in part A of Table 1. The test confirms the non-stationarity of these series; both series are however stationary in the first differences without trends.

As indicated previously in section II, a unidirectional Granger-causality test from oil consumption to oil spill is necessary to establish the appropriateness of a transfer function model. The result of the pairwise Granger-causality test is

[1] The general formulation is $\Delta y_t = \mu + \gamma y_{t-1} + \alpha t + \delta_1 \Delta y_{t-1} + \ldots + \delta_{p-1} \Delta y_{t-p+1} + \varepsilon_t$; and $H_o: \gamma = 0$, $H_1: \gamma < 0$, where μ is a constant, t is time trend, Δ is the difference operator, and all other terms have the usual definitions.

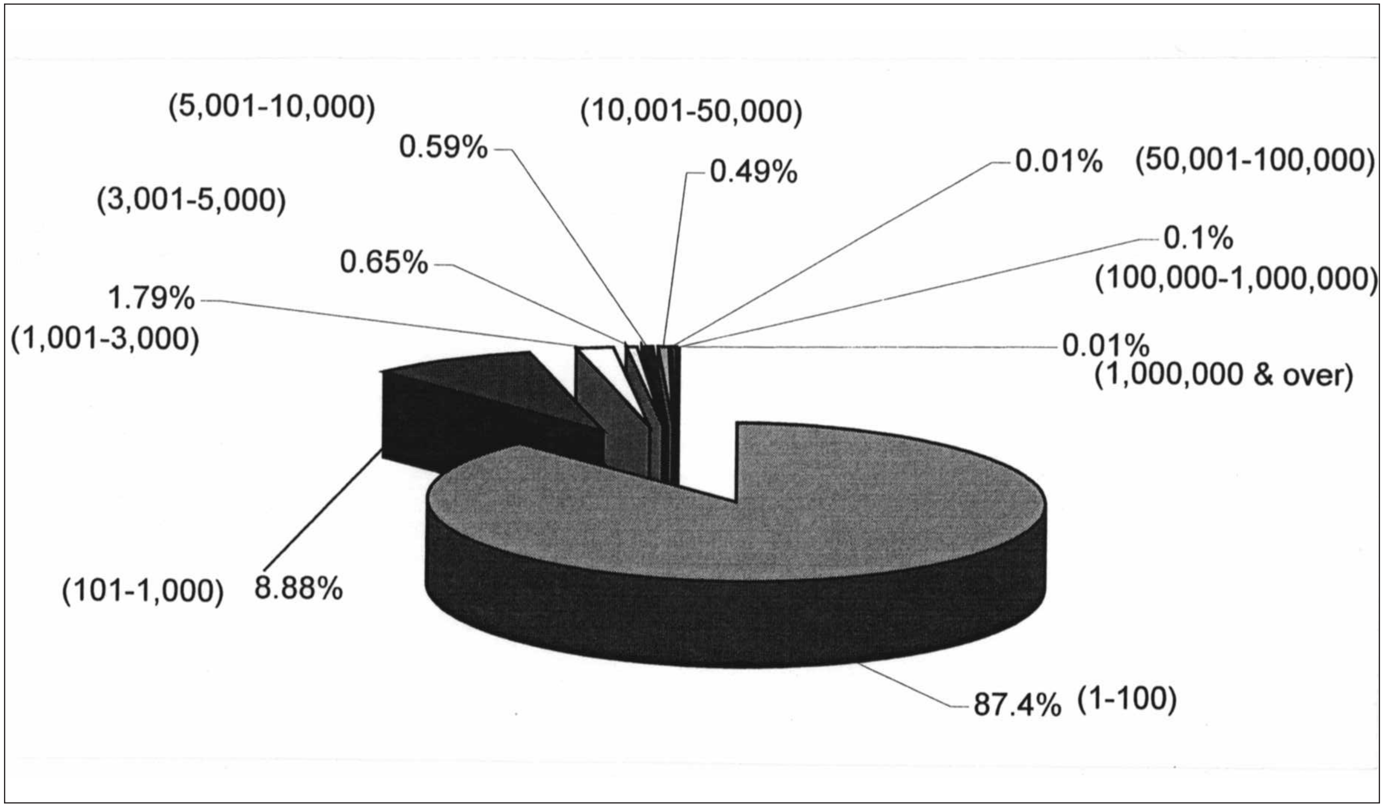

Figure 3. Average distribution of oil spill accidents by size—in gallons (1973-2000).

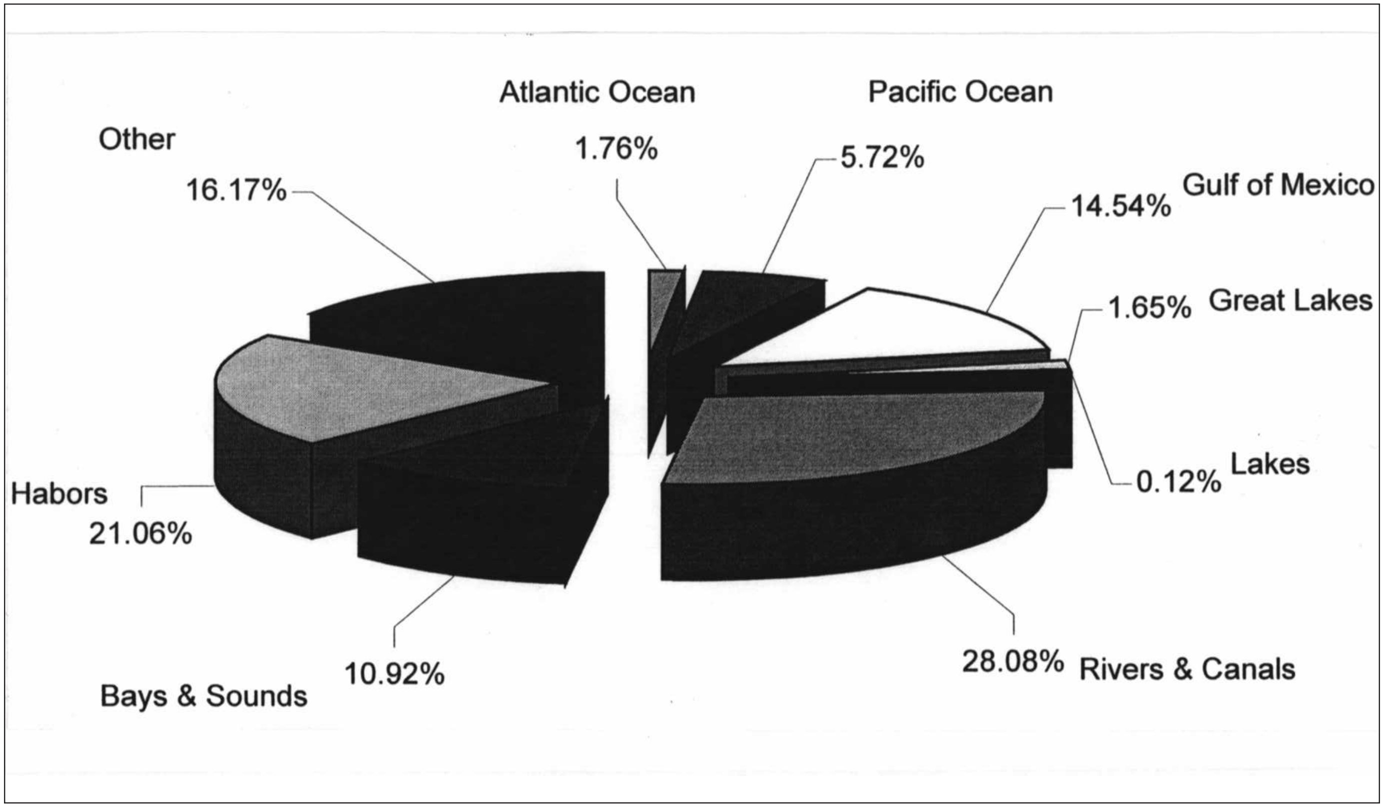

Figure 4. Average distribution of oil spill accidents by waterbody (1973-2000).

Table 1. Unit Roots and Granger-Causality Test Results

A. Unit Root Test

Variable	ADF test statistics	Probability
loil	–1.7171	0.423
dloil	–3.9049	0.002
lspills	–1.8080	0.376
dlspills	–4.8480	0.0001

B. Granger Causality Test

Null hypothesis	*F*-statistics	Probability
dlspill does not Granger cause *dloil*	1.1114	0.3438
dloil does not Granger cause *dlspills*	2.0550	0.017

Note: No. of observations: 298, No. of lags: 12.

depicted in part B of Table 2. The test strongly rejects causality from oil spills to oil consumption but strongly accepts causality from oil consumption to oil spills, suggesting that a transfer function model is appropriate in this case.

Given the above results, the general transfer function model employed is compactly depicted as follows:

$$A_i(B)dlspills = \mu_t + C_i(B)dloil_t + D_t(B)\varepsilon_t, \tag{8}$$

where $A_i(B)$, $C_i(B)$, and $D_i(B)$ are polynomials in the backshift operator B; μ is the "mean," which must be significantly different from zero when estimated if the first differenced series in Equation (8) is stationary, *dlspills* and *dloil* are the log-transformed first difference series for oil spills and oil consumption, respectively. The model is estimated using data from 1973-1997. Data from 1998 to 2000 are used to evaluate forecasting performance of the model.

In estimating Equation (8) the following steps are followed:

i) ARIMA procedures described above are followed to fit the series *dloil.* Several alternative plausible models are evaluated using three different criteria: Akaike Information Criterion (AIC), Schwartz Bayesian Criterion (BIC), and the likelihood ratio test (LR). The residuals are evaluated using standard plots and the Box-Ljung test statistics.

ii) Estimate a model of *dloil* series by pre-whitening it with the model finally chosen in (i) and evaluate its adequacy using available diagnostic examination of the crosscorelations between *dlspills* and *dloil.* Then, interpret the crosscorelations to tentatively identify a transfer function model.

(iii) Several plausible alternative transfer functions model identified by the error process of the preliminary transfers function model are considered. Three transfer function models of spills incidents and oil consumption were then selected based on the AIC, BIC, and LR criteria. A final model was selected based on its forecasting performance using three other criteria: Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Theil's Inequality Coefficient or Theil's "U."

The final model estimated and selected for forecasting future levels of spill incidents is

$$\underset{}{(1 + \underset{(0.0571)^{***}}{0.1852}B^5 + \underset{(0.0583)^{**}}{0.1454}B^6 - \underset{(0.0583)^{***}}{0.1520}B^{12} - \underset{(0.0572)^{**}}{0.1285}B^{13})}\, dlspills_t = \underset{(0.0003)}{-0.0009} + (\underset{(0.2361)^{**}}{0.50176} + \underset{(0.2356)^{**}}{0.9193}B)\, dloil_{t-6} + (1 - \underset{(0.0468)^{***}}{0.6215}B)\varepsilon_t \tag{9}$$

Obs: 292 S.E.: 0.1425 AIC: –299.85 SBC: –270.43 Q(26) – Prob: 0.62.

*Standard errors of estimate are shown in parentheses. The notations *, **, *** indicate statistical significance at 10%, 5%, and 1%, respectively.*

The results in Equation (9) show the model is consistent with the underlying theory and adequate. In particular, the constant term is statistically insignificant at all conventional levels showing a confirmation of the Dickey-Fuller test of stationarity of the data in first differences. Also, the Q-statistics is insignificant at all lags (not reported) indicating a white noise process, which implies the tests of significance of the estimates are valid. All parameters, except for the constant, are significant at the 5% level.

The coefficient on *dloil* is significant and positive indicating that growth in oil consumption leads to growth in oil spill accidents. The transfer function estimate shows a six-period "delay effect" or "dead time." This delay effect implies that it takes less than six months for a significant shift in oil consumption to show up in increased oil spill incidents. This length of period might seem a little bit long but it must be remembered that this is an "average" time, because in reality it is likely that the lag-response will differ by spill source. For example, accidental spills in industrial facilities are likely to show up faster than in internal waters, which are likely to be faster than those occurring in the Oceans. In other words, the time it takes to meet a given change in demand for oil consumption differs by mode of delivery.

The coefficients on the AR terms indicate that this system has a *memory* with regard to spill incidents. The effect of any given change in oil consumption decays at the rate that is implied by the AR coefficients. A change in oil demand in this period has a direct effect on the number of oil spill incidents in six periods from now.

Table 2. Forecast (F) and Actual (A) Distribution of Oil Spill Accidents in U.S. Waters, 1998-2005

	1998 (F)	(A)	1999 (F)	(A)	2000 (F)	(A)	2001 (F)	2002 (F)	2003 (F)	2004 (F)	2005 (F)
Total	8,248	8,315	8,270	8,539	8,382	8,354	8,503	8,626	8,747	8,868	8,989
Size of spill (gallons):											
1-100	7,814	7,962	7,835	8,212	7,941	8,058	8,056	8,172	8,287	8,402	8,516
101-1,000	321	259	322	240	326	219	331	336	340	345	350
1,001-3,000	56	54	56	42	57	37	58	59	59	60	61
3,001-5,000	20	15	20	18	20	12	20	20	21	21	21
5,001-10,000	16	15	16	10	16	16	17	17	17	17	18
10,001-50,000	15	8	15	12	15	6	16	16	16	16	17
50,001-100,000	3	0	3	4	3	4	3	3	3	3	4
100,000-1,000,000	3	2	3	1	3	2	3	3	3	3	3
1,000,000 and over	0	0	0	0	0	0	0	0	0	0	0
Waterbody:											
Atlantic Ocean	132	109	133	148	135	150	137	139	140	142	144
Pacific Ocean	557	644	558	758	566	623	574	582	590	598	607
Gulf of Mexico	1,790	2,190	1,794	1,756	1,819	1,838	1,845	1,872	1,898	1,924	1,950
Great Lakes	181	119	182	129	184	96	187	190	192	195	198
Lakes	21	25	21	31	21	32	21	22	22	22	23
Rivers and canals	1,768	1,944	1,772	1,924	1,796	1,816	1,822	1,849	1,875	1,901	1,926
Bays and sounds	951	891	954	1,299	966	1,248	980	995	1,009	1,022	1,036
Harbors	918	790	921	907	933	801	947	961	974	988	1,001
Other	1,930	1,603	1,935	1,587	1,961	1,750	1,990	2,018	2,047	2,075	2,103

Location:											
Internal/headlands waters	3,770	3,688	3,780	4,110	3,832	3,814	3,887	3,943	3,998	4,054	4,109
Coastal (0-3 miles)	978	1,226	980	1,225	993	1,066	1,008	1,022	1,037	1,051	1,065
Contiguous zone (3-12 miles)	223	223	223	96	226	154	230	233	236	240	243
Ocean (12-200 miles)	984	1,172	987	1,124	1,000	1,188	1,015	1,030	1,044	1,058	1,073
Ocean general	350	392	351	372	356	341	361	366	371	376	382
General/other	1,943	1,614	1,948	1,612	1,974	1,791	2,003	2,032	2,060	2,089	2,117
Source:											
Tankship	146	104	146	92	148	111	151	153	155	157	159
Tankbarge	300	220	301	227	305	229	310	314	318	323	327
All other vessels	4,151	4,848	4,162	5,361	4,219	5,220	4,280	4,342	4,403	4,463	4,524
Facilities	1,390	937	1,394	1,019	1,413	1,054	1,433	1,454	1,474	1,495	1,515
Pipelines	47	45	48	25	48	25	49	50	50	51	52
All other non-vessels	509	571	510	571	517	566	525	532	540	547	555
Unknown	1,704	1,590	1,708	1,244	1,731	1,149	1,756	1,782	1,807	1,832	1,857

Given the robustness of the transfer function model of oil spill accidents, a forecast of future levels of spill incidents is undertaken. First, we obtain actual levels of oil consumption to assess the forecast performance of the model. For the three years for which actual data is available, the aggregated number of actual (forecast) of oil spill accidents are as follows—1998: 8,315(8,248), 1999: 8,539(8,270), and for 2000: 8,354(8,382). These estimates show 0.8%, 3.2%, and –0.34% divergence between actual and (forecast) levels for the three years, respectively. The model thus seems to be adequate in predicting the future levels of spill incidents. Second, the forecast of spill incidents to the year 2000 was based on a projected annual growth rate of 1.5% in oil consumption [20]. The annualized growth rate is transformed into monthly rates to construct the series from 2001 to 2005. The model is thus simulated assuming the growth rate is constant.

The monthly forecasts for each year are aggregated and reported in the first row of Table 2. To obtain the distributions by size, water body, location, and source shown in Table 2, some simplifying assumptions are made. It is assumed that the oil spill accident distribution across these categories will be, on the average, similar to the pattern observed since 1990 following the passage of OPA 90. It is also assumed that these average distributions will be constant until 2005. Using these average estimates, the aggregated forecast totals are distributed as shown in Table 2. As these results show, the distributions of the forecast for 1998 to 2000 compared to their actual levels are reasonably similar. These results show that no incident involving more than a million gallons of spill is expected until 2005; not more than three incidents of a 100,000 gallons or more in any one year are expected, and at most only 24 spill incidents in any one year will result in more than 10,000 gallons spilled.

A major concern to the public and the private sector is the cost of cleanup after an incident has occurred. To estimate the cleanup costs implication of the forecast levels of incidents, an estimate of per gallon cleanup costs in previous accidents is employed. In making these estimates, it is assumed that no major spill such as the Exxon Valdez will occur. These costs are based on "typical" spill incidents that have occurred in the past as reported in Financial Costs of Oil Spills in the United States [3].

The average costs used are based on spills that have occurred in the various characteristics and categories in Table 2 from the mid 1970s to the late 1990s. However, caution must be exercised in using these estimates, as the cost of cleanup varies widely between locations, type of oil spilled, time of the day, weather, and a myriad of other uncontrollable factors. The results of applying these estimates to the forecast levels of incidents are reported in Table 3. As shown, cost of cleanup may be as high as $7 billion over this period or as low as $155 million in 1997 dollars. These estimates do not include damage costs, which can be very substantial depending on where the spill occurs and the amount of oil involved.

Table 3. Estimated Cleanup Costs of Oil Spills in U.S. Waters
(Million 1997 Dollars), 1998-2005

	Cleanup cost		
Year	Low	Medium	High
1998	13.78	104.77	878.96
1999	13.82	105.05	881.31
2000	14.00	106.47	893.24
2001	14.21	108.01	906.14
2002	14.42	109.57	919.24
2003	14.62	111.11	932.14
2004	14.82	112.65	945.03
2005	15.02	114.18	957.93
Total	114.69	871.81	7,313.99

V. SUMMARY AND CONCLUSIONS

Oil spills accidents are a daily occurrence in the United States. The Exxon Valdez oil spill off Alaska coast sparked the U.S. Congress to enact the Oil Pollution Act of 1990 (OPA 90), which aims at reducing the occurrence of accidents as well as assigning responsibilities for clean-up costs and remediation. Previous studies on oil spills in the United States have focused on ex-post analyses and prediction of individual spill events and their potential consequences. As with the case with most accidents, it is very difficult to predict an oil spill event. However, with adequate data, this study has demonstrated that it is possible to generate a reasonable estimate of the aggregate number of future levels of oil spill incidents. An empirical model of the relationship between oil consumption and oil spill was developed using the familiar ARIMA framework. In particular, a transfer function model of oil spills incidents using oil consumption as input was utilized.

The results show that between 1998 and 2005 the number of oil spill incidents will vary between 8,248 and 8,989. Only a few (at most 24) incidents in any one-year during this period will involve more than 10,000 gallons of oil being spilled. The estimated total average cleanup cost may be as low as $115 million and as high as $7 billion in 1997 dollars by 2005.

This study shows that future spill incidents are not expected to increase dramatically over the next five years. This may be interpreted to mean that OPA 90 and other regulatory efforts at the state level are beginning to pay dividends.

Nonetheless, those concerned with the environment and the public in general must be aware that even at the forecast levels of spill incidents, substantial cleanup costs and damage to the environment is still a permanent feature of oil pollution in U.S. waters.

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