DETERMINANTS OF THE DAMAGE COST AND INJURY SEVERITY OF FERRY VESSEL ACCIDENTS

Wayne K. Talley*(1), Di Jin (2), Hauke KitePowell(3)

(1)Old Dominion University, U.S.A., wktalley@odu.edu
(2)Woods Hole Oceanographic Institution, U.S.A., djin@whoi.edu
(3)Woods Hole Oceanographic Institution, U.S.A., hauke@whoi.edu

*Corresponding author.

Abstract

This study investigates determinants of the property damage cost and injury severity of ferry vessel accidents. Detailed data of individual ferry vessel accidents for the 11-year time period 1991-2001 that were investigated by the U.S. Coast Guard are used to estimate ferry-vessel accident property damage cost and injury severity equations. Tobit regression is used to estimate the former equation and the ordered probit model is used to estimate the latter. Property damage costs include damage costs to the vessel itself, its cargo and contents, and other-property damage (e.g., damage to pier structures and waterfront facilities). Injury severity for a ferry vessel accident is measured as an ordinal variable – no injuries, non-fatal injuries and fatal injuries. Damage cost and injury severity of individual ferry vessel accidents are expressed as functions of the type of vessel accident, vessel characteristics, vessel operation phase, weather/visibility conditions, type of waterway, type of vessel propulsion, type of vessel hull construction and cause of vessel accident. The property damage estimation results suggest that allision, collision and fire ferry vessel accidents incur more vessel property damage cost per vessel gross ton than other types of accidents. The injury severity estimation results suggest that injury severity is greater when the ferry vessel accident is caused by human error as opposed to vessel and environmental factors.

1. Introduction

In the U.S., 134 million passengers travel annually on ferry vessels (Stoller, 1999). Ferry vessels may transport passengers or passengers and their vehicles (autos and trucks). Ferries that transport the latter are referred to as roll-on-roll-off ferries. Among ferries that transport passengers, 60% have a passenger carrying capacity of 200 passengers or less; 16% have a capacity of over 500 passengers (Wieriman, 2003).

The instability of roll-on-roll-off ferries is a safety concern (National Transportation Safety Board, 1989). These vessels have large openings that allow for the loading (roll-on) and the unloading (roll-off) of automobiles and other cargoes, thus precluding vertical watertight bulkheads that are standard features on most commercial vessels. If water gets in and causes a pronounced list, the ferry will capsize and sink. If loading doors are breached, 60% of roll-on-roll-off ferries will sink within ten minutes (Barnard, 1987).[1] Since 1987, however, stricter stability regulations for roll-on-roll-off ferries have been enacted.

A general safety concern for ferry vessels is human error in vessel operation. For example, New York's Staten Island ferries have been involved in numerous accidents over the last 25 years, resulting in injuries to hundreds of passengers; these accidents have often been attributed to human error such as inattentiveness, poor judgment and negligence by crew members (McIntire, 2003).

The purpose of this study is to investigate determinants of the severity of ferry vessel accidents. Not only will the severity of injury to passengers and crew members be investigated, but also the damage severity to the ferry, its cargo and contents, and other property. Will the severity of a ferry vessel accident be greater if associated with a certain type of vessel accident, vessel characteristic, operating phase, weather/visibility condition, waterway, vessel propulsion, hull construction and accident cause? While evidence suggests that human error is a major cause of ferry vessel accidents, is it also a major contributor to the damage and injury severity of ferry vessel accidents? The findings of this study may be found to be useful to policymakers in regulating the safety of ferry vessels, insurance companies in insuring ferry vessels, managers in managing the operation of ferry vessels and passengers in their decisions regarding the utilization of ferries.

The study is structured as follows: A model of the property damage and injury severity of ferry vessel accidents is presented in Section 2, followed by a discussion of the data in Section 3. Estimation procedures and results are detailed in Section 4 and 5, respectively. Estimated marginal effects are discussed in Section 6. Conclusions are set forth in Section 7.

2. THE MODEL

The damage severity incurred by a ferry vessel accident is measured by the accident's real property damage cost per vessel gross ton (DAMAGE SEVERITY) and is hypothesized (based upon the vessel accident literature) to vary with the *type of vessel accident, vessel characteristics, vessel operation phase, weather/visibility conditions, type of waterway, type of vessel propulsion, type of vessel hull construction*, and *cause of vessel accident*, i.e.,

DAMAGE SEVERITY = f(*type of vessel accident, vessel characteristics, vessel operation phase, weather/visibility conditions, type of waterway, type of vessel propulsion, type of vessel hull construction, cause of vessel accident)* (1)

The *type of vessel accident* includes an allision[2] (ALLISION), collision (COLLISION), equipment-failure (EQUIPFAIL), explosion (EXPLOS), fire (FIRE), flooding (FLOOD), grounding (GROUND) and a breakaway, capsize or sinking accident. The DAMAGE SEVERITY incurred by a vessel accident is expected to be greater for allision and collision vessel accidents given the speed of impact. Otherwise, the a priori relationship between type of accident and DAMAGE SEVERITY is indeterminate.

Vessel characteristics include vessel size (VSIZE), vessel age (VAGE) and whether the vessel is a U.S. flag vessel (USFLAG). The a priori sign of the relationship between DAMAGE SEVERITY and vessel size is indeterminate. Although larger vessels are expected to be more seaworthy (e.g., less susceptible to adverse weather), it is unclear once an accident occurs whether they will be more or less susceptible to damage than smaller vessels. The a priori sign of the relationship between DAMAGE SEVERITY and vessel age is positive, since vessel structural failure is expected to increase with age. A negative relationship is expected between DAMAGE SEVERITY and USFLAG, since the U.S. is a nation among nations with the highest vessel safety standards.

Vessel operation phase is described by whether the vessel was moored or docked (MOORDOCK), anchored (ANCHOR), towed (TOW), underway (UNDERWAY) or adrift at the time of the accident. Underway vessels are expected to incur greater DAMAGE SEVERITY than moored, anchored and docked or adrift vessels.

Weather is differentiated by whether high winds (HIGHWINDS), precipitation (PRECIP) and/or cold temperatures (COLD) exist at the time of the accident. *Visibility* is differentiated by whether the visibility was poor (POORVISIB) and by time of day, nighttime (NIGHT) versus daytime. Although adverse weather and visibility are expected to increase the risk of a vessel accident, their impact on vessel-accident property damage cost incurred is unclear.

Type of waterway includes a harbor (HARBOR), river (RIVER), coastal (COAST), ocean (OCEAN), lake (LAKE) or a bay waterway. The a priori relationship between DAMAGE SEVERITY and type of waterway is unclear. Although a ferry vessel is more likely to have an accident in the waterway where its service is concentrated, it is unclear whether the accident will incur greater property damage severity in this waterway.

Type of vessel propulsion for a ferry includes diesel (DIESEL), gasoline (GAS) and turbine (TURBINE). It is unclear, however, which of these propulsion sources are expected to result in greater vessel property damage severity. *Type of vessel hull construction* for a ferry may include an aluminum (ALUM), fiberglass (FIBERG), steel (STEEL) or wood (WOOD) hull. Since steel is the strongest of these materials, it is expected that a ferry constructed with steel will incur less vessel property damage severity, all else held constant.

The *cause of vessel accident* for a ferry may be a human (HUMAN) cause as opposed to an environmental or vessel cause.[3] Even though most vessel accidents are caused by human error, it is unclear which cause will result in greater vessel damage severity.

Replacing the explanatory variables in equation (1) with their measurement variables and then rewriting, one obtains the following DAMAGE SEVERITY reduced-form equation:

DAMAGE SEVERITY =
F(ALLISON,COLLISION,EQUIPFAIL,
EXPLOS,FIRE,FLOOD,GROUND,
VSIZE,VAGE,USFLAG,MOORDOCK,
ANCHOR,TOW,UNDERWAY,
HIGHWINDS,PRECIP, COLD,
POORVISIB,NIGHT,HARBOR,RIVER,
COAST,OCEAN,LAKE,DIESEL,GAS,
TURBINE,ALUM,FIBERG,STEEL,
WOOD,HUMAN) (2)

INJURY SEVERITY in a ferry vessel accident is expressed as a function of its DAMAGE SEVERITY, *type of vessel accident*, *vessel characteristics*, *vessel operation phase*, *weather/visibility conditions*, *type of waterway*, *type of vessel propulsion*, *type of vessel hull construction* and *cause of vessel accident*, i.e.,

INJURY SEVERITY = g(DAMAGE SEVERITY,*type of vessel accident*, *vessel characteristics*, *vessel operation phase*,*weather/visibility conditions*, *type of waterway*, *type of vessel propulsion*, *type of vessel hull construction*, *cause of vessel accident*) (3)

DAMAGE SEVERITY should have a non-negative effect on INJURY SEVERITY given that a damaged vessel does not necessarily result in injured occupants. Among *type of vessel accidents*, allision and collision accidents are expected to incur more injuries. Also, more injuries are expected to occur when precipitation weather and poor visibility exist. The a priori relationships between INJURY SEVERITY and *vessel characteristics, vessel operation phase, type of waterway, type of vessel propulsion, type of vessel hull construction* and *cause of vessel accident* are unclear.

Replacing the variables in equation (3) by the variables used to measure them and rewriting, one obtains the INJURY SEVERITY reduced-form equation:

INJURY SEVERITY= G(DAMAGE
SEVERITY,ALLISON,
COLLISION,EQUIPFAIL,EXPLOS,
FIRE,FLOOD,GROUND,VSIZE,
VAGE,USFLAG,MOORDOCK,
ANCHOR,TOW,UNDERWAY,
UNDERWAY,HIGHWINDS,PRECIP,
COLD,POORVISIB,NIGHT,
HARBOR,RIVER,COAST,OCEAN,
LAKE,DIESEL,GAS,TURBINE,
ALUM,FIBERG,STEEL,WOOD,
HUMAN) (4)

3. DATA

Equations (2) and (4) are estimated utilizing detailed data of individual ferry vessel accidents that were investigated by the U.S. Coast Guard during the 11-year time period 1991-2001 and extracted from the U.S. Coast Guard Marine Safety Management System (MSMS) database. Five MSMS data tables were merged to obtain the data set for this study. The five data tables include: the Marine Casualty and Pollution Master Table (cirt), the Marine Casualty Vessel Supplement Table (civt), the Vessel Identification Table (vidt), the Marine Casualty Weather Supplement Record (cwxt) and the Marine Casualty Causal Factors Table (ccft). Vessel accidents of foreign flag vessels occurred in U.S. waters; those of U.S. flag vessels are not restricted to any body of water, although most occurred in U.S. waters. A sample of 912 individual ferry vessel accidents is used in the equation estimations.

The DAMAGE SEVERITY incurred by a ferry vessel accident is measured by the accident's real property damage cost per ferry vessel gross ton and was obtained by dividing the nominal property damage costs by the U.S. Producer Price Index for all commodities (divided by 100). Producer Price Index data were obtained from various issues of Producer Prices and Price Indexes. Property damage costs include damage costs to the vessel itself, its cargo and contents, and other-property damage. These costs have been or will be incurred to restore damaged vessels, cargo and contents, and other property to their service and physical conditions that existed prior to a ferry vessel accident. They are actual or estimated damage costs provided by owners to Coast Guard investigating officers. Cost estimates are considered to be accurate subject to verification by investigating officers. Damages costs to vessels do not include the cost of salvage, cleaning, gas freeing, dry-docking or demurrage.[4] Other-property damage costs in a ferry vessel accident is a catchall for other vessel-accident related damages, i.e., damages other than those incurred by vessels and their cargo and contents, not including damage to the environment. Examples include damages to pier structures and waterfront facilities.

Variables used in the equation estimations and their specific measurements and descriptive statistics (mean and standard deviation) appear in Table 1. The mean statistic for the dependent variable DAMAGE SEVERITY reveals that a ferry vessel accident incurs approximately $42 (on average) in property damage costs per vessel gross ton. The mean statistics for the explanatory variables reveal that 7.2, 3.5, 68.0, 0.2, 1.9, 1.0 and 5.2% of the accidents were allision, collision, equipment-failure, explosion, fire, flooding and grounding accidents, respectively. The average size and age of a ferry vessel involved in an accident is 1,257 gross tons and 25.0 years.

Underway vessels represent 63.8% of the ferry vessel accidents; 94.0 and 96.7% of the accidents occurred when cold weather and poor visibility existed; and 2.9, 17.1, 60.2, 3.0 and 3.0% occurred in harbor, river, coastal, ocean and lake waterways, respectively. A human factor was the cause of 22.6% of the accidents.

4. ESTIMATION PROCEDURES

Given that a vessel accident does not necessarily incur damage, some of the observations of the dependent variable DAMAGE SEVERITY may be zero. If so, the distribution of DAMAGE SEVERITY observations will be left-censored. Consequently, parameter estimates for equation (2) obtained by using ordinary least squares, which ignores censoring, may be biased. Specifically, ordinary least squares fails to account for the qualitative difference between the limit (or zero) observations and the non-limit (or continuous) observations. Such bias is avoided by utilizing tobit regression analysis which explicitly accounts for censored dependent variables. “When data are censored, the distribution that applies to the sample data is a mixture of discrete and continuous distributions” (Greene, 1997, p. 960).[5]

Given the absence of information on INJURY SEVERITY, injury severity is defined as a latent variable INJURY SEVERITY$_{LV}$, where

$$INJURY\ SEVERITY_{LV} = f(\beta x) + \varepsilon \tag{5}$$

and x represents the above set of hypothesized independent variables, β is a vector of parameter coefficients to be estimated, and ε is a normally distributed error term with zero mean and unit variance. Although we cannot observe INJURY SEVERITY$_{LV}$, we do observe the ordinal injury severity variable ORDINJSEV (taking the value of 0, 1, or 2) which is positively related to injury severity such that

$$ORDINJSEV = 0$$
$$INJURY\ SEVERITY_{LV} \le 0$$

$$ORDINJSEV = 1$$
$$0 < INJURY\ SEVERITY_{LV} \le \mu$$

$$ORDINJSEV = 2$$
$$\mu < INJURY\ SEVERITY_{LV} \tag{6}$$

where μ is an estimable threshold parameter that distinguishes the injury severity of a ferry vessel accident, where the injury severity consists of non-fatal injuries (ORDINJSEV=1) and fatal injuries (ORDINJSEV=2). If ORDINJSEV=0, there are no injuries. Given the distribution assumptions on ε, the model defined in (6) is an ordered probit model with choice probabilities (Greene, 1997):

$$\Pr(ORDINJSEV = 0) = 1 - \Phi(\beta' x)$$

$$\Pr(ORDINJSEV = 1) = \Phi(\mu - \beta' x) - \Phi(-\beta' x)$$

$$\Pr(ORDINSJSEV = 2) = 1 - \Phi(\mu - \beta' x) \tag{7}$$

where μ > 0 to insure that all probabilities are positive. Note that as ORDINJSEV increases in value, injury severity increases, i.e., the order of injury severity is maintained.

Possible estimation bias from omission of relevant explanatory variables is addressed by including Coast Guard District, yearly and monthly binary variables (see Table 1) in the estimations. The ten US Coast Districts are represented by the binary variable DISTj, where j = 1, 2, 5, 7, 8, 9, 11, 13, 14 and 17. The 1st Coast Guard District covers the New England and New York Atlantic coast; the 2nd District covers the Midwest; the 5th District, the Mid-Atlantic coast (southern New Jersey to North Carolina); the 7th District, the Southern Atlantic coast (South Carolina to Florida); the 8th District, the Gulf coast; the 9th District, the Great Lakes; the 11th District, the California coast; the 13th District, the Pacific Northwest coast; the 14th District, Hawaii; and the 17th District, Alaska.

Estimation bias from the inclusion of DAMAGE SEVERITY as an explanatory variable in the estimation of the INJURY $\text{SEVERITY}_{\text{LV}}$ equation is addressed by using the instrumental-variable estimation technique. DAMAGE SEVERITY is the dependent variable in equation (2) and thus is assumed to have an error term. It is expected that this error term will be correlated with the error term in the INJURY $\text{SEVERITY}_{\text{LV}}$ equation, thereby resulting in estimation bias for the latter. The instrumental-variable estimation technique involves finding a variable that is highly correlated with DAMAGE SEVERITY, but at the same time uncorrelated with the error term of INJURY $\text{SEVERITY}_{\text{LV}}$. For this paper, this variable (or instrument) is obtained by regressing DAMAGE SEVERITY on all explanatory variables and using the estimated DAMAGE SEVERITY variable from this equation as the instrumental variable for DAMAGE SEVERITY.

5. ESTIMATION RESULTS

Table 2 reports the results from the estimations of equations 2 and 4 – tobit estimation results for the DAMAGE SEVERITY equation and ordered probit estimation results for the INJURY $\text{SEVERITY}_{\text{LV}}$ equation. The estimation results for statistically significant explanatory variables, constant terms, and Coast Guard District and monthly binary variables appear in Table 2.

Focusing initially upon the DAMAGE SEVERITY results, it can be seen that the model fits the data well. The chi-square statistic is 52.10, exceeding the 16.81 critical value necessary for significance at the .01 level for 6 degrees of freedom. The coefficients of the *type of accident* variables suggest that allision, collision and fire incur more ferry vessel-accident property damage cost per vessel gross ton than other types of ferry vessel accidents. The coefficients of the *vessel operation phase* variables suggest that moored, docked and underway ferries incur more unit property damage cost than when ferries are anchored and being towed.

For the ordered-probit injury severity equation estimate, the chi-square statistic is large and statistically significant at the .01 level. The estimation results suggest that injury severity is less for equipment-failure and grounding ferry vessel accidents than for other types of vessel accidents. This severity is also less when the accident occurs in the ocean and less for Coast Guard Districts 5 (the Mid-Atlantic coast) and 13 (the Pacific Northwest coast) than for other Coast Guard Districts. However, the injury severity is greater when the ferry vessel accident is caused by a human factor as opposed to vessel and environmental factors. Note that the coefficient for the instrumental variable, Estimated DAMAGE SEVERITY, is negative and highly significant, suggesting that there is no positive relationship between injury and property damage severities of ferry vessel accidents. This result coupled with that for cause of accident suggest that policy makers in seeking to reduce injury severity in ferry vessel accidents will find that policies that seek to reduce human causes of these accidents will be more efficacious than those that seek to reduce the property damage severity of ferry vessel accidents in reducing injury severity.

Remember that DAMAGE SEVERITY may include damage costs other than those to the vessel, e.g., damage costs to cargo, vessel contents, pier structures and waterfront facilities. The negative relationship between injury severity and estimated DAMAGE SEVERITY may thus be due to the fact that a vessel accident’s property damage costs have a large proportion of other-than-vessel property damage costs and these costs are negatively related to injury severity.

Recall that to insure positive probabilities, the threshold parameter μ must be positive. As reported in Table 2, the estimate of this parameter is positive and highly significant.

6. MARGINAL EFFECTS

Unfortunately, the tobit coefficients found in Tables 2 do not measure the correct change in the dependent variable from a change in an explanatory variable for non-zero observations of the dependent variable. However, these coefficients can be adjusted to obtain such measures. McDonald and Moffit (1980) show that the change in the dependent variable (for its observations above a limit such as zero) from a change in an explanatory variable in a tobit equation can be measured as the product of the explanatory variable's tobit coefficient and the adjustment factor "A":

$$A=\{1-\left[zf(z)/F(z)\right]-\left[f(z)^2/F(z)^2\right]\} \quad (8)$$

where, z represents an evaluation (at the means of the explanatory variables) of the tobit equation divided by the equation's standard error; f(z) is the unit normal density; and F(z) is the cumulative normal distribution function. We refer to the product of "A" and a given tobit coefficient as the latter's "adjusted tobit coefficient".

The adjusted tobit coefficients that correspond to the tobit coefficients in Table 2 are found in Table 3. These coefficients indicate that the vessel-accident property damage cost per vessel gross ton for ferry vessels is $41.94, $48.41 and $106.20 higher for allision, collision and fire accidents than for other types of ferry vessel accidents. The unit damage cost is $58.04 and $54.91 higher for moored/docked and underway ferry vessel accidents than for other phases of ferry vessel operation. Also, the unit damage cost is $40.20 higher in Coast Guard District 11 (the California coast) than in other Coast Guard Districts.

Although the signs of the estimated ordered probit coefficients provide information on whether changes in given explanatory variables increase or lower the injury severity of a ferry vessel accident, they do not provide information on the extent to which the underlying injury severity probabilities change. For example, what is the impact of changes in the explanatory variables upon the probability of a ferry vessel accident sustaining no injuries (ORDINJSEV=0) versus the probability of sustaining non-fatal injuries (ORDINJSEV=1).

For the ordered probit injury severity model, the marginal probability effects are:

$$\partial \Pr(ORDINJSEV = o) / \partial x_j = \\ -\phi(\beta' x)\partial(\beta' x) / \partial x_j$$

$$\partial \Pr(ORDINJSEV = 1) / \partial x_j = \\ [\phi(-\beta' x) - \phi(\mu - \beta' x)]\partial(\beta' x) / \partial x_j \quad \partial \mathrm{P}$$

$$\partial \Pr(ORDINJSEV = 2) / \partial x_j = \\ \phi(\mu - \beta' x)\partial(\beta' x) / \partial x_j$$
(9)

where ϕ is the standard normal density function. When $\beta'x$ is a linear function of x_j , the partial derivative $\partial(\beta'x)/\partial x_j$ is simply β_j , the coefficient of the explanatory variable x_j.

Suppose that an increase in x_j increases injury severity. Then the coefficient of x_j is positive. Thus via equation (9), an increase in x_j increases the probability of the highest injury severity category, ORDINJSEV = 2, and decreases the probability of the lowest injury severity category, ORDINJSEV= 0. However, we don't know the effect of x_j upon the probability of the injury severity category, ORDINJSEV = 1. This probability depends upon the extent to which some fatal-injury ferry vessel accidents shift into lower-injury categories and the extent to which some non-fatal-injury accidents shift into the no-injury category. This is seen in equation (9) by the weighted difference in the two standard normal density functions. Table 4 provides estimates of these marginal probabilities for the explanatory variables found in Table 2.

The estimated marginal probabilities in Table 4 indicate that among types of ferry vessel accidents, an equipment-failure accident has the highest probability of incurring no injuries, i.e., a probability of .2132. If the accident is caused by a human factor versus a vessel or environmental factor, the probability of the ferry vessel accident incurring non-fatal and fatal injuries increases by .0273 and .0003, respectively. Among Coast Guard Districts, ferry vessel accidents in Coast District 13 (the Pacific Northwest coast) have the highest probability of incurring no injuries, i.e., a probability of .0068. Among types of waterways, the ocean waterway has the highest probability of incurring no injuries, i.e., a probability of .0037.

7. CONCLUSION

This study has investigated determinants of the property damage and injury severities of ferry vessel accidents. Detailed data of individual ferry vessel accidents for the 11-year time period 1991-2001 that were investigated by the U.S. Coast Guard were used to estimate ferry vessel-accident property damage and injury severity equations. The former severity equation was estimated utilizing tobit regression and the latter utilizing ordered probit.

The property damage estimation results suggest that allision, collision and fire ferry vessel accidents incur more vessel property damage cost per vessel gross ton than other types of accidents. Also, these unit damage costs are higher for moored, docked and underway ferry vessel accidents than for other phases of vessel operation. The injury severity estimation results suggest that injury severity is greater when the ferry vessel accident is caused by a human factor as opposed to vessel and environmental factors. Also, injury severity is less in

Coast Guard Districts 5 (the Mid-Atlantic coast) and 13 (the Pacific Northwest coast) than in other Coast Guard Districts and less in an ocean waterway than in other waterways. In addition, the estimation results suggest that there is a negative relationship between ferry injury severity and damage costs per vessel gross ton which, in turn, suggests that there is no positive correlation between the injury and property damage severities of ferry vessel accidents.

The vessel-accident damage cost per vessel gross ton of $106.20 for fire accidents is greater than that for any other type of accident. This unit damage cost is $40.20 higher for Coast Guard District 11 than for other districts. If the accident is caused by a human factor, the probability of non-fatal and fatal injuries increases by .0273 and .0003, respectively. In summary, the results suggest that policy makers in seeking to reduce the injury severity of ferry vessel accidents will find that policies that seek to reduce the human causes of these accidents will be efficacious in reducing their injury severity but not policies that seek to reduce the damage severity of ferry vessel accidents.

ENDNOTES

1. For a discussion of the risk of roll-on-roll-off ferries incurring collision and grounding accidents see Otto, Pedersen, Samuelides and Sames (2002).

2. An allision accident occurs when a vessel strikes a stationary object (not another vessel) on the water surface. A collision accident occurs when a vessel strikes or was struck by another vessel on the water surface. A grounding accident occurs when the vessel is in contact with the sea bottom or a bottom obstacle.

3. Examples of human causes of vessel accidents as classified by the U.S. Coast Guard include stress, fatigue, carelessness, operator error, lack of training, error in judgment, lack of knowledge, inadequate supervision, psychological impairment and intoxication. Examples of environmental causes include adverse weather, debris, shoaling, submerged object and adverse current/sea condition. Examples of vessel causes include corrosion, dragging anchor, stress fracture, fouled propeller, steering failure, propulsion failure, auxiliary power failure and inadequate controls/displays/lighting. For further discussion of human and other causes of vessel accidents, see Abrams (1996), Millar (1980) and Staff (1998).

4. Demurrage is a charge by a carrier for the detention of equipment and cargo beyond the free period which is allowed for loading, unloading or other purposes.

5. For further discussion of tobit regression, see Greene (1997).

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Table 1
Variable Definitions and Descriptive Statistics

Variable	Measurement	Mean	Std. Dev.
Dependent Variable			
DAMAGE SEVERITY	real vessel-accident property damage $US cost per vessel gross ton	42.12	214.8
ORDINJSEV	0 if no vessel-accident injuries 1 if non-fatal vessel-accident injuries 2 if fatal vessel-accident injuries	.125	.367
Explanatory Variable			
Type of vessel accident*			
ALLISION	1 if an allision vessel accident, 0	.072	.259

	otherwise		
COLLISION	1 if a collision vessel accident, 0 otherwise	.035	.184
EQUIPFAIL	1 if an equipment-failure vessel accident, 0 otherwise	.680	.467
EXPLOS	1 if an explosion vessel accident, 0 otherwise	.002	.043
FIRE	1 if a fire vessel accident, 0 otherwise	.019	.138
FLOOD	1 if a flooding vessel accident, 0 otherwise	.010	.098
GROUND	1 if a grounding vessel accident, 0 otherwise	.052	.222
Vessel characteristics			
VSIZE	vessel size in gross tons	1257	1176
VAGE	vessel age in years	24.97	17.55
USFLAG	1 if a US flag vessel, 0 otherwise	.982	.135
Vessel operation phase			
MOORDOCK	1 if vessel is moored or docked, 0 otherwise	.199	.399
ANCHOR	1 if vessel is anchored, 0 otherwise	.002	.043
TOW	1 if vessel is towed, 0 otherwise	.002	.043
UNDERWAY	1 is vessel is underway, 0 otherwise	.638	.481
Weather/visibility conditions			
HIGHWINDS	1 if high winds exist (greater than 20 knots), 0 otherwise	.022	.147
PRECIP	1 if precipitation weather, 0 otherwise	.010	.098
COLD	1 if cold temperature (less than 32 Fahrenheit degrees), 0 otherwise	.940	.238
POORVISIB	1 if poor visibility, 0 otherwise	.967	.178
NIGHT	1 if nighttime, 0 otherwise	.016	.124
*Type of waterway***			
HARBOR	1 if a harbor, 0 otherwise	.029	.167
RIVER	1 if a river, 0 otherwise	.171	.376
COAST	1 if a coastal waterway, 0 otherwise	.602	.490
OCEAN	1 if an ocean, 0 otherwise	.030	.169
LAKE	1 if a lake, 0 otherwise	.030	.071
*Type of vessel propulsion****			
DIESEL	1 if vessel is under diesel propulsion, 0 otherwise	.942	.234
TURBINE	1 if vessel is under turbine propulsion, 0 otherwise	.015	.122
*Type of vessel hull construction*****			
ALUM	1 if aluminum hull construction, 0 otherwise	.145	.353
1IBERG	1 if fiberglass hull construction, 0 otherwise	.016	.126
STEEL	1 if steel hull construction, 0 otherwise	.832	.374
WOOD	1 if wood hull construction, 0 otherwise	.005	.068
Cause of vessel accident			
HUMAN	1 if a vessel accident was initially caused by a human factor, 0 otherwise	.226	.418
Coast Guard district			

DIST1	1 if district one, 0 otherwise	.205	.404
DIST2	1 if district two, 0 otherwise	.005	.068
DIST5	1 if district five, 0 otherwise	.138	.345
DIST7	1 if district seven, 0 otherwise	.063	.243
DIST8	1 if district eight, 0 otherwise	.104	.306
DIST9	1 if district nine, 0 otherwise	.042	.200
DIST11	1 if district eleven, 0 otherwise	.068	.252
DIST13	1 if district thirteen, 0 otherwise	.365	.482
DIST14	1 if district fourteen, 0 otherwise	.001	.030
DIST17	1 if district seventeen, 0 otherwise	.009	.096
Year			
Y91	1 if year 1991, 0 otherwise	.004	.061
Y92	1 if year 1992, 0 otherwise	.074	.262
Y93	1 if year 1993, 0 otherwise	.088	.284
Y94	1 if year 1994, 0 otherwise	.088	.284
Y95	1 if year 1995, 0 otherwise	.098	.298
Y96	1 if year 1996, 0 otherwise	.115	.319
Y97	1 if year 1997, 0 otherwise	.096	.295
Y98	1 if year 1998, 0 otherwise	.114	.317
Y99	1 if year 1999, 0 otherwise	.109	.312
Y00	1 if year 2000, 0 otherwise	.133	.340
Y01	1 if year 2001, 0 otherwise	.081	.273
Month			
M1	1 if January, 0 otherwise	.079	.270
M2	1 if February, 0 otherwise	.065	.247
M3	1 if March, 0 otherwise	.087	.282
M4	1 if April, 0 otherwise	.071	.257
M5	1 if May, 0 otherwise	.090	.287
M6	1 if June, 0 otherwise	.089	.284
M7	1 if July, 0 otherwise	.109	.312
M8	1 if August, 0 otherwise	.106	.307
M9	1 if September, 0 otherwise	.082	.275
M10	1 if October, 0 otherwise	.081	.273
M11	1 if November, 0 otherwise	.072	.258
M12	1 if December, 0 otherwise	.069	.254

*Other types of accidents in our data include breakaways and sinkings.

**Our data also include the category “other waterways.”

***Other types of propulsion in our data include sail and “other propulsion type.”

****Other types of hull construction in our data include plastic and “other hull material.”

Table 2
Ferry Vessel-Accident Equation Estimates*

Explanatory Variable	DAMAGE SEVERITY**	INJURY SEVERITY$_{LV}$***
Type of accident		
ALLISON	92.62 (3.06)	----
COLLISION	106.9 (2.38)	----
EQUIPFAIL	----	-2.7355

		(-6.96)
FIRE	234.5 (3.95)	----
GROUND	----	-2.0940 (-5.43)
Vessel Operation Phase		
MOORDOCK	128.2 (3.56)	----
UNDERWAY	121,3 (3.87)	----
Cause of accident		
HUMAN	---	1.0197 (5.13)
Coast Guard District		
DIST5	----	-.5323 (-1.86)
DIST11	88.79 (2.84)	-----
DIST13	---	-.7799 (-3.19)
Type of waterway OCEAN	---	-.6319 (-1.71)
Estimated DAMAGE SEVERITY	---	-.0138 (-5.71)
Constant	-166.0 (-5.50)	.6686 (2.38)
Ordered Probit Parameter, μ	--	1.5852 (8.71)
# of Observations	912	912
Chi-Square Statistic	52.10	260.9

* t statistics are in parentheses.
** tobit regression estimate.
***ordered probit estimate.

Table 3
Marginal Damage Effects of Ferry Vessel Accidents

Explanatory Variable	DAMAGE SEVERITY
ALLISION	41.94
COLLISION	48.41
FIRE	106.20
MOORDOCK	58.04
UNDERWAY	54.91
DIST11	40.20

Table 4
Marginal Injury-Severity Probabilities of Ferry Vessel Accidents

Explanatory Variable	S = 0[a]	S = 1[b]	S = 2[c]
EQUIPFAIL	.2132	-.2045	-.0087
GROUND	.0057	-.0056	-.0000
HUMAN	-.0276	.0273	.0003
DIST5	.0039	-.0039	-.0000
DIST13	.0068	-.0068	-.0000
OCEAN	.0037	-.0037	-.0000
Estimated DAMAGE SEVERITY	.0002	-.0002	-.0000

a Change in the probability of no injuries.
b Change in the probability of a non-fatal injury.
c Change in the probability of a fatal injury.