Public Policy Towards Offshore Oil Projects: Confronting Potential Deepwater Oil Spills

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Abstract: There has been a recent surge in global interest in drilling offshore wells in pursuit of new reserves of crude oil. Much of this activity is focused on deepwater. One concern related to this uptick in activity is the potential for very large damages that could follow a blowout. For example, when the Macondo well in the Gulf of Mexico suffered a blowout in 2010 oil flowed from the well into the Gulf for nearly three months; in total nearly 5 million barrels of oil were released into the environment, causing enormous harm. In the aftermath of this event, the United States Government proposed significant regulatory changes related to offshore oil and gas exploration and production. In this paper I propose a framework for thinking about the risks associated with deepwater exploration and production, and then use information on the potential benefits to construct an estimate of willingness to pay in terms of the induced reductions in risk. While the costs of the proposed regulations are very large, plausibly running into billions of US Dollars, a case can be made that willingness to pay exceeds these costs provided society is sufficiently risk averse.

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1 Introduction

Over the past year, increases in global crude oil demand combined with supply disruptions attributable to the war in Ukraine had induced key changes in crude oil markets. One particularly noteworthy effect is the ensuing increase in exploration for, and production from, large offshore deposits of crude (Henderson, 2023). This trend has been amplified by sluggish US shale production, along with global subsidence of the COVID pandemic. Further, because deposits in shallower waters have been more thoroughly exploited, a considerable amount of attention has been directed towards deep-water oil deposits. Much of the action in deep-water reserves is tied to West Africa and Brazil, along with the Gulf of Mexico. Indeed, these three areas accounted for nearly two-thirds of the approximately 100 deep water contracts undertaken in 2022 (Henderson, 2023).

While this source of production can be prolific there are important risks associated with it; in particular, oil spills occurring in deep water can be hard to contain, leading to significant economic harm. This possibility is most notoriously illustrated by the 2010 blowout of the Macondo well in the Gulf of Mexico (associated with the offshore drilling unit "Deepwater Horizon") and the subsequent oil spill. Oil flowed from the well into the Gulf of Mexico for 87 days. The extended and substantial flow of oil caused direct and indirect economic harm, primarily in the Gulf of Mexico region. Recent estimates indicate well over 1,000 miles of shoreline have been contaminated (Nixon et al., 2016). The volume of oil released into the environment was the largest ever recorded from an offshore spill in the history of the United States (US), and was the third largest spill ever observed globally.[1] Potentially impacted individuals include participants in the gulf coast fishing industry (Sumaila et al., 2012), individuals employed in the tourism industry, (Eastern Research Group, 2014; Oxford Economics, 2010; Ritchie et al., 2014) and property owners (Siegel et al., 2013). The perception of substantial harm naturally leads to concerns about the potential for large damages from future spills, which in turn triggered calls for more stringent standards governing offshore oil and gas activities.

In response to these concerns, the US Government adopted new rules governing offshore oil and gas exploration and production on 29 April, 2016.[2] Primarily, these new regulations strengthened "blowout preventer" (BOP) characteristics, features designed to bring a well back under control following an incident, features requiring shear rams be designed to include a technology that allows the drill pipe to be centered during shearing operations,[3] requirements of more rigorous third-party certification of the shearing capability of the BOP, and requirements for real-time monitoring of deepwater wells.

Appraisals of the likely cost of these regulations varies dramatically between

[1] The court determined that 3.19 million barrels of oil were released into the environment, placing it behind the oil spill associated with the first Gulf war (roughly 11 million barrels) and the Lakeview gusher, an out of control blowout that occurred in Kern County, California in 1910 (roughly 9 million gallons). See http://geology.com/articles/largest-oil-spills-map/ for discussion.

[2] "Oil and Gas and Sulfur Operations in the Outer Continental Shelf-Blowout Preventer Systems and Well Control", 81 FR 25887, Federal Register pp. 25887-28038; at `https://www.federalregister.gov/documents/2016/04/29/2016-08921/oil-and-gas-and-sulfur-operations-in-the-outer-continental-shelf-blowout-preventer-systems-and-well?utm_campaign=subscription%20mailing%20list&utm_medium=email&utm_source=federalregister.gov`.

[3] Shear rams are designed to sever the drillpipe following an incident, thereby staunching the flow of oil. It is believed that the shear ram mechanism failed following the Macondo blowout, thereby allowing oil to flow from the wellbore.

industry and government sources. The agency that promulgated this set of regulations, the Bureau of Safety and Environmental Enforcement (BSEE), puts the costs less than $100 millions per year, while the American Petroleum Institute (API), a key industry lobbying organization, argues the costs will be in the range of $3 billions per year.[4] With over 300 wells drilled offshore in a typical year during the period after the Macondo oil spill, the API estimate can be interpreted as a cost approaching $10 Million per well.

Because the new regulations are likely to impose significant costs, it is natural to ask how large the damages from the Macondo spill were. One way to estimate of the magnitude of these damages would be to collect massive amounts of data, for example by instituting a rigorous survey scheme. To illustrate such an approach, a number of well-known scholars discussed in detail the survey designs that were constructed and executed to assess various damages associated with the spill at the recent annual conference of the Association of Environmental and Resource Economists. Scores of economists were involved in the process, which took years to complete. In the end, then, such a detailed approach seems likely to have been costly and difficult. It also bears the stigma, fairly or not, associated with the use of survey methods to assess values, as well as the need to properly define a broad set of affected households to whom the survey estimates would be extrapolated.[5]

[4] See Bureau of Safety and Environmental Enforcement (2016) and Quest Offshore (2015). The APT report was published more than 9 months before release of the final rule; during this period, a variety of adjustments to regulation were undertaken in response to stakeholder input. As such, the final proposed regulation was less onerous than the version evaluated by API, so that Quest Offshore (2015) almost surely overstates the costs of the new regulations.

[5] A detailed description of the approach taken, and the rationale for that approach, are available in NOAA Total Value Team (2016a) and NOAA Total Value Team (2016b). Petrolia (2014) surveys some analyses of various alternative economic impacts that have arisen from the oil spill.

An alternative, less complex, method relies on publicly available information related to claims programs that were undertaken in response to the oil spill, and so is significantly less costly to undertake. Using this data, I estimate the order of magnitude of economic harm associated with the spill to be roughly 14.5 billion US Dollars. My estimate is roughly comparable to the detailed estimate obtained by the NOAA Total Value Team, which is in the range of $20 billions (Bishop et al., 2017).

The final element in this inquiry is an evaluation of the risks associated with deepwater exploration and production. Using data taken from the BSEE website, I argue that the risk of an incident rises substantially as endeavors push into deeper water. In light of this pattern, and the plausible level of annual drilling going forward, a compelling argument in support of the new regulations can be made.

I start the discussion in section 2, with a conceptual societal problem associated with the desire to manage the risk of a dramatic adverse event linked to deepwater offshore drilling. This leads to a characterization of societal willingness to pay to mitigate the risk of a particular bad event. Fleshing out the economic considerations requires developing a sense for the magnitude of damages that could obtain, as well as a probabilistic description of such an outcome; I offer a discussion of these attributes in sections 3 and 4, respectively. I present a numerical simulation linked to these elements in section 5; here I illustrate the potential magnitude of willingness-to-pay, as a portion of economic product for the region in question. To place these values in context I compare them agains the estimated costs of the

In general, these reflect substantially smaller amounts than the damages assessed by NOAA Total Value Team (2016a), or indeed than the amounts I articulate in the text below.

regulations described above. Section 6 offers concluding remarks.

2 Conceptual analysis of risks from offshore oil

The essential features of our problem can be captured by the following stylized model: an individual well is contemplated, where there are three possible events that could occur after the well is drilled: *event 0* (no spill), *event 1* (small spill) or *event 2* (large spill). Associated with each event $i = 1, 2, 3$ are the outcomes D_i and probabilities p_i, where $D_0 = 0, D_2 > D_1 > 0$ and $p_0 + p_1 + p_2 = 1$. In the specific application I will also assume p_2 is small and D_2 is considerably larger than D_1. A social planner is tasked with managing the risk associated with the drilling venture. For now I assume this planner approaches this task by evaluating the expected utility tied to the lottery over damages implied by the probability vector (p_0, p_1, p_2) and vector of outcomes (D_0, D_1, D_2); later I will discuss the implications of relaxing the assumption that the planner uses expected utility to evaluate the prospect.

I start by assuming there is a level of societal wealth (perhaps some measure of gross product, net of any environmental of financial damages resulting from a spill) that I denote as V. Under event 0 there are no damages, and so wealth remains at V. Under event $i = 1, 2$ there is a spill, and associated damages arise. It will be convenient to interpret these damages as a fraction of wealth (one can think of the spill as destroying some of the initial wealth), which I write as $D_i = \delta_i V$. Also, because the three probabilities must sum to one, we may replace the probability p_1

with the expression $1-p_0-p_2$. Using this notation, the planner's objective function is expected utility

$$EU(p_0, p_2) = p_0 u(V) + (1 - p_0 - p_2) u\Big((1-\delta_1)V\Big) + p_2 u\Big((1-\delta_2)V\Big), \tag{1}$$

where $u(\cdot)$ is the von Neumann-Morgenstern utility function that summarizes the risk attitude governing the decision. Because the potential damages are large, I presume the planner exhibits at least some aversion to risk, which implies that u is concave.

Now imagine the planner can institute some sort of policy that costs a fraction of initial wealth $1-\gamma$ and that lowers the chance of a big spill occurring, conditional on there being a spill. One might think of regulations that require certain prophylactic safeguards be put in place that mitigate against a large spill resulting when conditions trigger a spill. This policy can be thought of as a form of social insurance. Writing the new, lower probability associated with event 2 as βp_2, expected utility in this context becomes

$$EU(p_0, \beta p_2; \gamma) = p_0 u(\gamma V) + (1 - p_0 - \beta p_2) u\Big((1-\delta_1)\gamma V\Big) + \beta p_2 u\Big((1-\delta_2)\gamma V\Big). \tag{2}$$

In principle, one would want to identify the "optimal" level of social insurance, *i.e.* that combination of (β, γ) that maximizes expected utility. In the pursuant discussion, I focus on the somewhat less ambitious investigation: that is the societal "willingness to pay" to reduce the risk of event 2 to a specified fraction β of the original level of risk. This more focused query is motivated by the sense that actual policies might be influenced by a variety of political factors, in which case it remains useful to determine whether the policy would pass a cost-benefit test. Put slightly differently, is the actual cost of the policy smaller than the societal willingness to pay (in which case the policy has positive net benefits). This inquiry reduces to determining the relation $\hat{\gamma}(\beta)$ with the property that $EU(p_0, \beta p_2; \hat{\gamma}(\beta)) = EU(p_0, p_2)$:

$$p_0 u(V) + (1 - p_0 - p_2) u\Big((1 - \delta_1)V\Big) + p_2 u\Big((1 - \delta_2)V\Big) =$$
$$p_0 u(\gamma V) + (1 - p_0 - \beta p_2) u\Big((1 - \delta_1)\gamma V\Big) + \beta p_2 u\Big((1 - \delta_2)\gamma V\Big). \quad (3)$$

It is easy to see that $\hat{\gamma}(1) = 1$ and $\hat{\gamma}'(\beta) < 0$.

To delve deeper into the investigation, one would have to impose further structure, say by specifying a particular functional form for $u(\cdot)$. To that end, I suppose the utility function satisfies constant relative risk aversion, *i.e.* that

$$u(x) = \kappa x^{\omega},$$

where $0 < \omega < 1$ to ensure concavity of $u(x)$. Adopting this functional form in the context of eq. (3), and noting that the component κV^{ω} appears in every term, the expression for $EU(p_0, \beta p_2; \hat{\gamma}(\beta)) = EU(p_0, p_2)$ can be written as

$$p_0 + (1 - p_0 - p_2)(1 - \delta_1)^{\omega} + p_2(1 - \delta_2)^{\omega} = \hat{\gamma}^{\omega}\Big[p_0 + (1 - p_0 - \beta p_2)(1 - \delta_1)^{\omega} + \beta(1 - \delta_2)^{\omega}\Big]. \quad (4)$$

From this expression, it is straightforward to derive willingness to pay as

$$1 - \hat{\gamma}(\beta) = \left[\frac{p_2(1-\beta)\Big((1-\delta_1)^{\omega} - (1-\delta_2)^{\omega}\Big)}{p_0 + (1-p_0)(1-\delta_1)^{\omega} - \beta p_2\Big((1-\delta_1)^{\omega} - (1-\delta_2)^{\omega}\Big)} \right]^{\frac{1}{\omega}}. \tag{5}$$

A key feature of the problem described above is that there is a potentially significant consequence that occurs comparatively infrequently. The potential for a low probability high-consequence event is important: for some time, economists have recognized that expected utility may perform poorly under such circumstances (Machina, 1982, 2006). The key extension here is to replace a representation that is linear in probabilities with one that is *non-linear* in probabilities; a simple way to operationalize these characteristics is by setting $W(p_0, p_2) = a_0 p_0 + a_1 p_2 + b_0 p_0^2 + b_1 p_0 p_2 + b_2 p_2^2$, where $a_0 > 0 > a_2; b_0 \leq 0, b_1 \leq 0, b_2 \leq 0$ and at least one of the b_k parameters is strictly negative.[6] Parallel to the thought process applied in the previous sub-section, willingness to pay to lower the odds of the bad outcome (a major oil spill) can be characterized by:

$$W\Big(p_0, p_2\Big) = W\Big(p_0, \beta p_2; \gamma\Big).$$

The complication is that the coefficients, particularly a_1 and b_2, are likely to change as a result of the up-front costs associated with the newly adopted policy. That noted, the typical characterization of such a non-linear representation is an increase in willingness to pay to mitigate risk.

[6] Since event 0 is the best possible outcome and event 2 is the worst possible outcome, anything that makes event 0 more likely or event 2 less likely should yield higher well-being.

3 Economic Harm from the Spill

Conceptually, the amount of lost income due to the oil spill would be the difference between businesses' and individuals' actual earnings and what they would have earned in the period after April 20, 2010 had the oil spill not occurred. An obvious proxy for individuals or businesses earnings had the oil spill not occurred is earnings preceding the spill. An estimate of harm can then be made by comparing the earnings realized after the spill against the earnings that the business or individual realized during the period before the spill.[7]

There were two major programs that assessed harms from the spill. From August 2010 until June 2012, claims were processed by the Gulf Coast Claims Facility (the "GCCF Program"). After June 2012, claims were processed by the Deepwater Horizon Court Supervised Settlement Program (the "Settlement Program").[8] Both the GCCF and the Settlement Program compared post-spill income or profits to pre-spill levels. Many claims used the average of 2007, 2008 and 2009, or the average of 2008 and 2009, or 2009 as the benchmark period. Individuals who changed

[7] An alternative approach would be to forecast underlying trends relevant to each individual, for example by analyzing in detail the industry they participate in. This alternative method would be complex and unwieldy when so many claims had to be processed, likely leading to very large transactions costs.

[8] BP conducted a third, and minor, claims program operated briefly before the GCCF became operational. A description of the BP claims program is available at "Gulf of Mexico Oil Spill - Claims and Other Payments - Public Report - July 31, 2015", which may be downloaded at http://www.bp.com/content/dam/bp-country/en_us/PDF/GOM/Public-Report-July-2015.pdf. A summary of the BP claims program, as well as the GCCF program, is contained in BDO Consulting (2012). The full legal document describing the Settlement program is contained in "Deepwater Horizon Economic and Property Damages Settlement Agreement as Amended on May 2, 2012, Rec. Doc. 6430-1", which can be accessed at http://www.deepwaterhorizoneconomicsettlement.com/docs/Amended_Settlement_Agreement_5.2.12_optimized.pdf.

jobs between the base period and 2010, or who started work on or after April 21, 2009 had to include 2011. In the Appendix I describe in greater detail these programs; here I summarize the key information regarding alleged damages.

Table 1 describes the spatial distribution of payments under the GCCF. Here, I list claims paid and monies disbursed to each of the five states, differentiated between coastal counties and inland counties. One would expect substantially larger damages in the coastal counties, as they bore the brunt of the impacts from the spill; the table clearly supports this conjecture. For Alabama, Louisiana and Mississippi – the three states that were most directly exposed to the spill – both the number of claims and monies paid out were roughly two orders of magnitude larger for the average coastal county than for the average inland county. The Florida panhandle counties were also directly impacted, though counties farther south were largely spared exposure; as such, the dichotomy between coastal and inland counties and inland counties is a bit smaller than with Alabama, Louisiana and Mississippi. In Texas, where the coast was far less exposed to the spill, the distinction between coastal and inland counties is smaller still. In total, over $7.5 billion was paid out under the GCCF.[9]

Under the Settlement Program, claimants were required to establish causation for certain claims, though causation was presumed for other claims. However, even where causation was presumed, claimants had to show an economic loss

[9] A simple linear regression shows that population, presence in the "Gulf Coast Area" and presence in a coastal county all exerted positive and statistically significant impacts on both the number of claims paid and the amount of money disbursed. All else equal, Coastal counties exhibited markedly larger effects than did Gulf Coast Area counties. These results are available in an online appendix; the appendix also contains a map containing a color-coded display of total claims payments under the GCCF, across counties in the five state region.

in the period following the oil spill as measured by reduced income or reduced profits in the period after the spill as compared to an earlier benchmark period. In defining the benchmark period, most claimants were allowed to use either 2009, the average of 2008 and 2009, or the average of 2007, 2008 and 2009 to form their benchmark.[10] As with the GCCF, the foundation for any losses assessed was the difference in earnings before and after the spill occurred.

Table 2 display some relevant statistics for the Settlement Program.[11] Here, I display the aggregate amount offered, the total amount of accepted offers, and the total amount paid, for each claim type; entries are listed in decreasing order of monies offered. Business Economic Losses are the most important category, while the second most import category is the Seafood Compensation Program. Combined, these top two categories represent about 5/6 of all monies offered, and of all money offers accepted. In total, over 87,000 unique claimants were paid over $7 billions under the Settlement Program.

This method may somewhat overestimate or underestimate the precise amount of economic harm experienced by an individual or entity due to the oil spill because the benchmark period earnings may be slightly lower or higher than the earnings that the individual or business would have realized but for the spill. Businesses experience natural variations in their income or profits from year to year, for example because of variations in weather or patronage. The volume of fish caught

[10] Individuals who changed jobs between the base period and 2010, or who started work on or after April 21, 2009 had to include 2011 in their benchmark period. See www.deepwaterhorizoneconomicsettlement.com/docs/QRG_IEL.pdf.

[11] This table was constructed using information drawn from reports filed by the claims administrator. These reports were posted for every month between September 2012 and May 2016. I use data from the most recent report (Juneau, 2016).

vary, as do the prices the fish fetch, from one year to the next; hotel room rentals vary from one year to the next; tourism generally is subject to variations in receipts from one year to the next. There are also broad-based macro-economic trends that may impact all industries within a particular region. All these effects, which are external to the oil spill, may make the benchmark period earnings slightly different from the earnings that the business would have realized but for the spill. Allowing individuals to average income levels over multiple years, as in both the GCCF and the Settlement Program, can average out any cyclical macroeconomic factors or unusual weather events to find a reasonable forecast as to what one could expect to earn in the period of interest, had the oil spill event not occurred.

While the difference between the benchmark period and post-spill income or profits may include elements that are due to external factors, it does capture differences in income or profits that are due to the oil spill. Each individual claim can therefore be viewed as an estimate of that individual claimant's loss, which might be either an under- or an over-estimate of damages. Aggregating the claims paid that were calculated using this method provides a rough estimate of damages to claimants caused by the oil spill.[12]

With this interpretation in mind, each claim payment is a measure of an individual or business's economic harm, either for some past loss or in anticipation

[12] Hanley et al. (2007, pp. 334-336) discuss the aggregation of damage estimates across affected individuals. One can also think of these individual damages as estimates of an individual's loss; the set of claims can then be used to estimate the average loss suffered by an individual in the set (Asteriou and Hall, 2011; Chou, 1989). Then multiplying by the total population in the Gulf of Mexico would produce an estimate of total damages. Since one cannot know how the set of individuals who did not file claims were impacted, I prefer to use the simper method of summing reported claims.

of a future stream of losses. As such, the sum of payments reflects an estimate of total harm. This sum would include the payments during the brief period where BP processed claims, and the two more substantial programs associated with the GCCF and the Settlement Program. Table 5 lists all these payment programs. The sum of these payments then defines an estimate of the economic harm from the Macondo oil spill: nearly $14.5 billions.

4 Well Failure Probability

In this section I characterize the *ex ante* likelihood of a spill. To this end, I collected publicly available data on offshore oil spills. These data, available from the BSEE website, identify all spills exceeding 50 barrels prior to 2013.[13] This information includes the data of the spill, the water depth, the amount spilled, and the cause of the spill. Some spills result from hurricanes or failed pipelines; because the new regulations focus on drilling activities, *i.e.* exploration for and development of new deposits, I exclude these spills from consideration. Other spills are caused by ships such as barges; again, these are not relevant to the inquiry at hand, and so I exclude them. After filtering the observations in this manner, I retain observations on 76 spills over 276 months.

Figure 1 plots the time and water depth associated with these spills, while Figure 2 shows the average depth and number of wells drilled, for each year between 1990 and 2012. Two patterns are apparent: comparing the period after

[13] While the data go back to the 1960s, technology facilitating deep water drilling was unavailable prior to 1990. I therefore limit my focus to observations between1990 and 2012.

2000 to the period before 2000, spills become more common and they occur in deeper water over time. These features are likely the result of the increased drilling that occurred after the turn of the century, when oil prices started to rise; this lead to a more attractive economic climate in which to explore, and also accommodated more costly ventures (such as deep water exploration).

Because the volume of drilling is trending upward during the sample period, it is not immediately obvious that spill rates are changing. To get at that issue, I plot the number of spills per well drilled in Figure 3. Here, I split out larger spills – those in excess of 1,000 barrels – from smaller spills. While smaller spills are more common, on the order of five times as likely as larger spills, both are becoming more likely over time. Moreover, the general trends towards increased spill rates are roughly the same.

Because oil spills arising from drilling are relatively infrequent, using ordinary least squares to evaluate patterns is ill-advised. A better approach is to use a "count regression", such as a Poisson or Negative Binomial model. Evidence from such a regression model is given in Table 7. The left-side variable in this analysis is the number of non-minor oil spills in a given month.[14] Right-hand side variables reflect drilling activity and the depth of a typical well drilled in a given month; I consider two measures: average depth of wells drilled in a month, or the number of wells drilled in water deeper than 1,000 feet in a month.[15]

The key result here is that spills are more common the deeper are wells, and

[14] The BSEE data characterizes spills as "minor", "medium" or "major". As there are relatively few major spills I retain medium spills in the inquiry, but do not consider minor spills.

[15] This depth is widely considered to delineate between more conventional wells and "deep water wells".

the more wells are drilled. Indeed, my results indicate that a 100 foot increase in average well depth is expected to increase the number of spills by 5.7%. To put this in context, the average well depth in 2012 (the last year of the sample) is slightly more than 1,000 feet greater than the sample used in these regressions (1,890 vs. 875 feet); this difference is similar to the increase between 2005 and 2012. Accordingly, one might anticipate the number of spills in 2012 was roughly 57% larger than the sample average. Alternatively, Figure 2 points to an increase in average depth of 500 feet, year-on-year. As such, one would expect the rate of spills is increasing by roughly 28.5% each year.[16]

5 Numerical example

In this section I construct a numerical example using the various pieces of information produced in the preceding sections. The focus is on calculating willingness to pay for reducing the probability of a large spill, based on eq. (5). To operationalize that formula, one needs values for various parameters: p_0, p_2, δ_1 and δ_2. I perform these calculation for three values of ω, which is related to the index of relative risk

[16] For the sample used in these regressions, the average number of spills in a typical month is 0.275, suggesting a spill would occur about every four months. As the average depth between 2005 and 2012 increased by roughly 125 feet per year, the expected number of spills would be expected to increase by about 7.1% per month, or about 85% per year, going forward. Muehlenbachs et al. (2013) provides corroborating evidence to these conclusions, though they base their analysis on all spills. Their results point to a sharp increase in spill rates as wells are drilled in deeper water, with a predicted spill rate of about 30% for a well drilled in 5,000 – which is roughly the water depth of the Macondo well. By contrast, I do not consider spills BSEE characterized as "minor". Anderson et al. (2012) find similar results, although their analysis includes spills resulting from Hurricane Rita, while I exclude Hurricane-related spills.

aversion.[17] The three values used are .25, .5 and .75. For each of these three values I calculate the willingness to pay for a range of levels of risk reduction, β.

I start the construction of this example by choosing the level of damages from an oil spill. For the level of damages from a large spill I use the value identified in section 3: \$14.5 billion. For a smaller spill, I employ information from two recent offshore spills in the U.S., both of which occurred on the coast of California. In 2015 a spill occurred near the community of Refugio when an undersea pipeline ruptured; this lead to a spill of 3,400 barrels that was estimated to have caused \$69 million in harm. In 2021 a spill occurred near the community of Orange city; here, 3,110 barrels were released into the environment, with an estimated harm of \$50 million. Taking the two levels of harm together with the volume released, one obtains an average effect of these spills per barrel released equal to \$1,828. If we interpret a small spill as one that is between 500 and 1,000 barrels, consistent with the information discussed in section 4, we obtain an estimate of damage between \$909,282 and \$1,818564;

To interpret these values as percentages, one needs a baseline level of wealth. For the large spill, I use the average over the five year period from 2010 to 2015 for gross state products in the four gulf coast states that were most directly impacted by the Macondo oil spill. This value is \$330.698 Billion. For the smaller spill, I use the average state product for California in the period between 2015 and 2021; this is close to \$3,000 Billion. Combining these baseline values with the damage estimates in question, I obtain estimates of the fractional harms $\delta_1 \approx .000001$ and

[17] In particular, the index of relative risk aversion is 1 - ω.

δ_2 = .044.

The next task is to identify the relevant probabilities. Using the information from section 4 there were 7 large spills between 2000 and 2011 with about 8,700 wells drilled, suggesting $p_2 \approx .0007$. During this period, there were 53 smaller spills, suggesting $p_1 \approx .006$. Thus, $p_1 = .993$.

With these parameters in hand, one can calculate willingness-to-pay to reduce risk for a range of levels of risk reduction β (with 1 - β interpreted as the fractional reduction in p_2). The results from such a numerical exercise are presented in Table **??**. In this diagram, I plot the willingness to pay against fractional reduction of p_2 for three levels of relative risk aversion. The solid line shows this plot for an index of relative risk aversion equal to .75; this is the highest level of risk aversion in the set of three values. The dashed line shows this plot for an index of relative risk aversion equal to .25; this is the lowest level of risk aversion in the set of three values. The long-dashed line shows this plot for an index of relative risk aversion equal to ., an intermediary level of risk aversion. For each of the three values we see that willingness-to pay increases as β falls (meaning a larger reduction in p_2). Further, willingness-to-pay is increasing in aversion to risk, as one would expect. To place these values in context, the value of willingness-to-pay for a 50% reduction in the probability of a severe spill is a little over .005%, viewed as a fraction of state GDP. In this exercise I used an estimate of state GDP equal to \$330.698 Billion, meaning the willingness to pay for such a reduction would be slightly more than \$16.5 Million. By comparison, the per-well cost implied by industry estimates, as discussed in the introduction, is less than \$10 Million per well. On this basis, one could argue that the proposed regulations would make economic sense if they would have lead to a 50% reduction in the chance of a major incident, *i.e.*à reduction of this probability from $\approx .0007$ to $\approx .00035$.

6 Conclusion

Large numbers of individuals and businesses suffered economic harm as a result of the Macondo oil spill. Many of the losses were direct, in that they reflect reductions in income or profit as a direct result of the spill. There were also indirect losses (the impacts resulting from the change in spending by those who suffered direct effects upon industries that provide goods and services to those in the direct effects cohort) and induced losses (resulting from reduced household income of anyone in the primary or related industries, for example laborers who lose their jobs as a result of the initial direct effect upon their employer). One way to think about the combination of these effects is as a decomposition of payments to factors of production: when a particular firm is adversely impacted, payment to the firm's owner will fall, as will payments to the various factors of production; the first element reflects reduced profits while the second set of elements combine to describe reductions in the firm's costs. Summing these describes the reduction in revenues, which is equivalent to reductions in payments by customers. In this way, the combination of harms to sellers is dual to harms suffered by potential buyers. Altogether, almost $14.5 billion was paid in claims to individuals and businesses.

Using actual claim payments as a measure of economic harm due to the oil spill excludes some damages. Some harms were explicitly excluded from the Settlement Program, including claims of BP shareholders, claims for moratoria losses, claims relating to Menhaden fishing and processing, and claims for economic damage suffered by entities in the banking, gaming, financial, insurance, oil and gas, real estate development, and defense contractor industries, as well as claims from entities selling or marketing BP-branded fuel. Some individuals or businesses who experienced economic losses may have determined that the likely return from filing was not worth the time and cost of filing the claim. The time and cost of filing a claim are examples of transactions costs. There are indications that the transactions costs associated with filing a claim as part of the GCCF and Settlement Programs could be substantial.[18] Any individual or business that suffered damages less than the transaction costs would rationally decide to not file a claim. Others may have overestimated the transaction costs and decided that it was not worthwhile to file, even they would have received more claims money than the true cost associated with filing the claim. It has also been argued that psychological impacts associated with an event such as the Deepwater Horizon oil spill could be substantial (Fewtrell and Kay, 2008). Finally, some types of harm were not explicitly excluded from the three claims programs but no claim was available for these harms. For instance, the claims paid do not reflect recreational use losses, or various non-market losses such as losses of ecosystem services. These

[18] Austin et al. (2014, p. 164) reports the GCCF often claimed to have lost the documentation provided by claimants, and “claims adjusters made multiple, new requests for additional financial documents, stretching over weeks and months.”

latter losses have been estimated in the range of $20 billions.[19] On the other hand, the nature of the claims process was such that many small claims were paid under the so-called "quick payment" option. These claims were not subject to scrutiny, and so these claim payments may have overstated damages. That noted, the total amount paid out under this option was quite small in comparison with the total damages outlined above, and so any over-estimate of damages would have been minor in comparison to my estimate of total damages.

Weighing against these large losses are the tangible and large costs associated with the regulatory program promulgated in response to the spill. These costs have been estimated to lie between $ 700 million and $ 3 billion annually, which corresponds to roughly between $.25 and $8.7 millions per well. Thus, a reduction in the probability of a major oil spill of .00025 would generate non-negative net benefits. While evaluating the impact of the regulations upon the risk of a major spill is impractical, one can characterize the nature of oil spill risks prior to the promulgation of the regulations. These risks are rising over time, specifically as a result of drilling in ever deeper waters.

An alternative to invoking new regulations might be to insist that drillers are liable for any damages caused by a spill for which they are responsible. While such an approach is conceptually compelling there are some important practical limitations. First, litigation costs can skew incentives away from the claimed

[19] See Bishop et al. (2017) for discussion. Farrow and Larson (2012) propose an intriguing approach to identifying a lower bound on non-use damages, via the time individuals allocate to viewing news stories about an event such as the Deepwater Horizon oil spill. In their application, the authors estimate passive use effects associated with the Exxon Valdez oil spill were in the range of $10 - 30 Millions.

efficiency of setting the charge for an offense equal to its expected damage (Shavell, 2014). In the case at hand, the action brought against BP under the Clean Water Act took over three years to litigate, with substantial expenses incurred by all parties. In the end, BP settled the case (along with the prospective case involving natural resource damages, and all cases brought by the five impacted states) for about $18.5 billions. This settlement split payments between the impending resource damages case and the concluded Clean Water Act case by ascribing $5.5 billion to the Clean Water Act case. This is noteworthy, as BP was exposed to a potential finding in excess of $13 billions. Thus, the settled amount fell far short of BP's exposure. The ascribed amount corresponding the natural resource damages was $8.5 billions, far less that the amount estimated by Bishop et al. (2017). The inescapable conclusion is that the settlement probably did not impose the complete costs of the spill upon BP. Second, the nature of possible damages is such that the expected value is almost surely much larger than any realized damage (Viscusi and Zeckhauser, 2011).

A Appendix: Details of the Claims Processes

A.1 *Background*

The operator of the Macondo well was BP Exploration and Production – a wholly owned subsidiary of BP. In the aftermath of the Macondo blowout and ensuing oil spill, BP was charged with violating the Oil Pollution Act, to which BP pled guilty. The implication was that BP was responsible for compensating those who suffered economic harm as a result of the oil spill (Goldberg, 2010). As I noted in section2, three programs assessed harms from the spill: a claims program was operated directly by BP from May to August 2010; the "Gulf Coast Claims Facility" (GCCF) operated from August 2010 until June 2012; and the the Deepwater Horizon Court Supervised Settlement Program (the "Settlement Program") operated from June 2012 to July 2015.

A.2 The BP Claims Program

The BP Claims Program received over 154,000 claims, and made over 127,000 payments to more than 30,000 claimants (BDO Consulting, 2012, p. 12). The total amount paid was slightly less than $400 million. Claims processed included health related effects, adverse impacts to fisheries, real estate losses, property damage losses, tourism losses, and lost wages. Claimants were required to provide documentation to support their claim, such as documentation to establish their lost income, their commercial economic loss, and their property damage. BP extensively reviewed claims processed by the claims adjusters and forensic accountants hired to run the BP Claims Program. The BP Claims Program provided payments for past losses only; it did not issue payments to cover future anticipated losses. The BP Claims Program was suspended on August 22, 2010.[20]

[20] At the conclusion of the GCCF, BP resumed paying a small number of claims directly; these payments totaled $11.8 million.

A.3 The GCCF

The GCCF Program commenced on August 23, 2010. It processed claims involving lost earnings or profits for individuals and businesses, damage to real or personal property, loss of subsistence use of natural resources, as well as removal and clean-up costs, and physical injury or death. Hundreds of trained claims processors processed these GCCF claims.

The GCCF Program was split into two phases. The first phase, known as "Phase I," processed claims for documented losses sustained during the first six months following the Macondo blowout; the focus was on quick disbursement of funds, which was accomplished by a claims process known as "Emergency Advance Payment." During this phase, claims payments accelerated dramatically in comparison to the BP Program. Funds paid out during this phase reflected damages suffered to that point; in particular, recipients were not required to waive future rights. The second phase, "Phase II," processed three types of payments: quick payment, interim payment and final payment. The quick payment claim involved a modest one-time payment of $5,000 for individuals or $25,000 for businesses; claimants were required to sign a form promising not to bring future suits against BP. Interim and final payments involved compensation for documented past losses or damages caused by the Spill. These claims were incremental to any past claims, either from the BP Program or from Phase I of the GCCF. Interim payments were limited to losses sustained by the claimant up to the date the claim was filed; there was no attempt to quantify anticipated future losses. By contrast, final payments included both past losses and an estimate of future losses. To make a claim, an individual had to demonstrate that the loss had been proximately caused by the oil spill, and had to provide evidence as to the magnitude of the loss.[21]

Figure 5 displays the payment history during the BP Claims Processing period and the first 16 months of the GCCF.[22] While claims increased sharply during the first phase, it is noteworthy that significant amounts of money were paid out on a month-by-month basis during Phase II. While the figure is truncated at the end of 2011, claims were accepted through June 2012. At that time, claims were handled under the Court Sponsored Settlement Program.

A.4 The Settlement Program

Towards the end of 2011, a class action suit against BP was gathering momentum. Such a proceeding would likely be costly and time consuming, and entailed substantial risk – for both potential plaintiffs and for BP. Recognizing these risks, the parties negotiated a settlement in mid-April 2012. An amended version of this agreement was filed with the court in early May, and was sanctioned on December 21, 2012.[23] Claims started being processed under the Settlement Program in July of 2012.

The Settlement Program addressed many types of individual and business economic losses, losses in real property value, and subsistence losses. Claims under

[21] See Gulf Coast Claims Facility (2010). While receiving an interim claim did not entail releasing BP from future liability, claimants receiving a final payment were required to sign a form promising not to bring future suits against BP.

[22] Reproduced from Figure 2 in BDO Consulting (2012, p. 60).

[23] A copy of the amended agreement can be accessed at www.deepwaterhorizonsettlements.com/Documents/Economic%20SA/Settlement_Agreement.pdf, and a copy of the Court's order can be accessed at www.deepwaterhorizonsettlements.com/Documents/Econ%20Order%20Granting%20Final%20Approval.pdf.

the Settlement program fell into 12 categories: Seafood Compensation Program; Individual Economic Loss; Individual Periodic Vendor or Festival Vendor Economic Loss; Business Economic Loss; Start-Up Business Economic Loss; Failed Business Economic Loss; Coastal Real Property; Wetlands Real Property; Real Property Sales; Subsistence; Vessels of Opportunity Charter Payment; and Vessel Physical Damage. The Economic and Property Damages (E&PD) Settlement Class includes people, businesses, and other entities in the "Gulf Coast Area" that were harmed by the oil spill.[24] Claims eligible for payment under the E&PD include Seafood Compensation, Economic Damage, Loss of Subsistence, Vessel Physical Damage, Coastal Real Property Damage, Wetlands Real Property Damage, and Real Property Sales Damage. Both claimants and BP had the right to appeal proposed claim settlements.[25]

A.5 Mechanics of the claims processes

Under both the GCCF and the Settlement Program, claimants were required to provide documentation of any alleged losses. For example, individuals making claims related to lost real or personal property under the GCCF were required to provide "[i]nformation or documentation showing the value of the property both before and after damage"; for lost profits or earning capacity, the individual was required to provide "[i]nformation concerning the Claimant's lost profits or

[24] This area consists of states of Louisiana, Alabama and Mississippi, and the counties of Chambers, Galveston, Jefferson and Orange in the state of Texas, and the counties of Bay, Calhoun, Charlotte, Citrus, Collier, Dixie, Escambia, Franklin, Gadsden, Gulf, Hernando, Hillsborough, Holmes, Jackson, Jefferson, Lee, Leon, Levy, Liberty, Manatee, Monroe, Okaloosa, Pasco, Pinellas, Santa Rosa, Sarasota, Taylor, Wakulla, Walton and Washington in the state of Florida.

[25] BP's appeals were limited to claim payments in excess of $25,000.

earnings that were caused by the injury, destruction, or loss of specific property or natural resource as a result of the Spill (such as lost earnings by a fisherman whose fishing grounds have been closed or a hotel or rental property that has had decreased profits because beaches, swimming, or fishing areas have been affected by the oil from the Spill)" (Gulf Coast Claims Facility, 2010, p. 3). For claims related to mitigation expenses, the individual was required to demonstrate that "[t]he actions taken were necessary for removal of oil discharged due to the Spill or to prevent, minimize, or mitigate oil pollution from the Spill" and that "[t]he removal costs incurred as a result of these actions are reasonable and necessary" (Gulf Coast Claims Facility, 2010, p. 2). The GCCF Program was quite rigorous; indeed, over 60% of claimants who filed under the GCCF were denied.

GCCF claims processing involved sorting claimants into one of four categories (BDO Consulting, 2012, pp. 37, 39-40):

1. individuals and businesses that depended heavily on resources and tourism from the Gulf and who were located in zip codes that bordered the Gulf shore;

2. individuals and businesses from Gulf Alliance counties who were not located in zip codes that bordered the Gulf shore, along with businesses that located in zip codes bordering the Gulf that were not heavily reliant on Gulf resources and tourism;

3. claimants that were not located in the Gulf Alliance counties, or who were not heavily reliant on Gulf resources and tourism;

4. and claimants who were deemed not deemed not to be eligible for compensation by the GCCF.

If an individual claimant was found eligible, his or her losses were determined by comparing actual 2010 earnings against projected 2010 earnings. Projected 2010 earnings were the highest of the claimant's earnings for 2008, 2009 or annualized 2010 prior to the Spill, which were then seasonally adjusted. The resultant amount was then subtracted from the claimant's actual earnings to determine the claim payment. For Final Payment claims less than $500,000 or more, the analysis included a prediction of future losses. These predicted future losses were incorporated by a "Future Recovery Factor," which was based upon a multiple of the claimant's documented 2010 loss amount; as such, one can think of this component as reflecting an estimate of the expected present discounted value of future damages. For claimants with documented 2010 losses of $500,000 or more, the GCCF did not automatically apply a Future Recovery Factor (BDO Consulting, 2012, pp. 35, 41, 43).

A.6 Appeals processes

A legitimate concern with both the GCCF and the Settlement Program is that not all claims submitted were valid, which could potentially taint the expository value of claims paid. To the extent that there is any indication that claims were carefully evaluated, such concerns are at least partly addressed. As I noted above, well over half the claims filed under the GCCF were denied, pointing to a rigorous evaluation process. More detailed evidence is available under the Settlement

Program. Table 3 shows the number of claim forms filed, the number of claims that were denied, and the fraction of claims denied, by claim type (arrayed in the same order as in Table 2). Of the 342,230 claims that were filed under the program, 124,596 were denied, corresponding to a 36.4% rejection rate. Some categories, such as property markets and vessel damage, had smaller denial rates, perhaps because such claims were easier to evaluate (and hence parties with questionable claims would be less prone to seek compensation). In other categories, including failed and startup business loss, claims would be much harder to substantiate (as causation would be trickier to establish); denial rates in these categories exceed 50%. Significantly, the claims category with the largest monetary outlay – Business Loss – had a denial rate of roughly 1/3. Overall, the magnitudes of these denial rates offer at least casual empirical support for the conjecture that claims were subject to a rigorous evaluation.

Further evidence regarding the claims evaluation process under the Settlement Program comes from results from its appeals process. As I noted above, both BP and claimants had the opportunity to appeal the specific claims. Both BP and claimants appealed roughly 23% of the claims that were eligible for appeal (Juneau, 2016, p. 9). Overall, slightly more than 9,800 appeals were filed; of these, with roughly 3/4 of those filed by BP (Juneau, 2016, Table 5, p. 3 in Exhibit A). Table 4 displays statistics from the appeals process under the Settlement Program. Here, I split out the number of appeals processed, together with the number of appeals that resulted in higher or lower payments; for reference, I also include the number of claims paid and amount of monies paid; all these values are reported by claims category. The first point to be made is that the lion's share of appeals result in no change in payment – of the more than 9,800 appeals processed, less than 2,000 resulted in an adjusted payment. Conditional on the appeal changing the amount paid, downward revision was more common than upward revision; these lower outcomes correspond to slightly more than 1/6 of appeals processed.

A.7 Interpretation

One way to view the negotiated settlement is as the result of a bargaining process (Posner, 1973). Let V_d represent the expected value of damages resulting from trial, as estimated by the defendant (here, BP), and V_p represent the expected value of damages resulting from trial, as estimated by the plaintiff (here, the collection if individuals in the certified class); let T_d (respectively, T_p) represent the expected transactions costs associated with litigation that would be borne by the defendant (respectively, plaintiff). There will be a negotiated settlement so long as $V_p - T_p$ (the net amount the plaintiff anticipates receiving if the case goes to trial) is smaller than $V_d + T_d$ (the net amount the defendant anticipates paying if the case goes to trial). In this event, the negotiated settlement can fall anywhere between $V_p - T_p$ and $V_d + T_d$; the ultimate settlement equals damages plus a residual term that depends on the two parties' bargaining strengths. While this discussion models the interaction between a defendant and a single plaintiff, the logic applies equally well if there is a group of plaintiffs, as in a class action suit. In that case, the estimated damages are based on the groups' aggregated damage, and the transactions costs are based on the combined costs of all group members; nothing else of substance is different from Posner's scenario.

This general framework can be applied to any point of contention during the pre-trial bargaining; in particular, one can think of such a process governing the methods used to assess claims, to establish causation, to project future expected damages, and to deal with appeals. As a result, and because the parties involved in the negotiations had no reason to accept a deal they felt was disadvantageous, the resultant mechanism should be informative about parties' beliefs regarding the accuracy of agreed upon methods for assessing damages. The fact that most appeals were denied is at least broadly corroborative of this conjecture.

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Table 1: Claims and Money Paid under the Gulf Coast Claims Facility, by state

	inland		coastal	
state	claims	money	claims	money
Alabama	100.4	1.732	21353.3	361.368
	(199.4)	(3.791)	(18982.1)	(338.909)
Florida	182.1	3.246	9007.2	125.792
	(347.9)	(5.290)	(11574.)	(165.957)
Louisiana	296.4	7.516	14437.8	190.960
	(654.577)	(13.625)	(21498.2)	(210.246)
Mississippi	54.3	1.856	12738.7	173.082
	(117.1)	(3.172)	(10714.7)	(138.763)
Texas	51.6	2.903	872.7	22.524
	(213.8)	(19.420)	(739.4)	(18.433)
Total	39449	1092.818	456437	6473.731

notes: (i) payments in millions of US Dollars
(ii) standard errors in parentheses

Table 2: Claim Payments under the Settlement Program

Claim Type	Amount Offered	Amount Paid	Unique Claimants Paid
Business Economic Loss	$4,823,992,442	$4,138,333,122	25,468
Seafood Compensation Program	$1,668,618,866	$1,623,142,601	5,107
Wetlands Real Property	$215,209,396	$183,320,081	1,791
Subsistence	$186,235,260	$147,474,466	16,909
Coastal Real Property	$163,875,138	$157,093,781	22,358
Start-Up Business Economic Loss	$147,717,900	$136,184,385	824
Individual Economic Loss	$82,863,827	$76,191,272	6,229
Real Property Sales	$40,478,745	$40,405,448	759
Vessel Physical Damage	$12,497,839	$12,249,222	744
Failed Business Economic Loss	$5,388,575	$3,323,958	38
Individual Periodic Vendor or Festival Vendor Economic Loss	$77,085	$77,085	8
Total	$7,346,955,073	$6,517,795,421	80,235

Table 3: Claims Denied under the Settlement Program

Claim Type	Total Claims	Total Denied	% Denied
Business Economic Loss	114,051	37,464	32.8%
Seafood Compensation Program	30,565	8,820	28.9%
Wetlands Real Property	20,103	7,348	36.6%
Subsistence	58,593	15,081	25.7%
Coastal Real Property	42,296	8,507	20.1%
Start-Up Business Economic Loss	7,292	3,851	52.8%
Individual Economic Loss	58,880	38,209	64.9%
Real Property Sales	3,110	934	30.0%
Vessel Physical Damage	1,553	471	30.3%
Failed Business Economic Loss	5,314	3,601	67.8%
Individual Periodic Vendor or Festival Vendor Economic Loss	473	310	65.5%
Total	342,230	124,596	36.4%

Table 4: Claims Filed, Paid and Appealed under the Settlement Program

Claim Type	Claims Filed	Claims Paid	Appeals Processed	Payments Adjusted Higher	Payments Adjusted Lower
Business Economic Loss	133,076	27,633	7,617	73	1,501
Subsistence	67,691	16,909	44	4	1
Individual Economic Loss	60,781	6,229	470	28	72
Coastal Real Property	42,128	28,478	264	38	1
Wetlands Real Property	27,317	7,016	133	3	10
Seafood Compensation Program	24,953	12,768	444	82	22
Start-Up Business Economic Loss	7,733	874	0	0	0
Failed Business Economic Loss	5,614	38	0	0	0
Real Property Sales	3,065	857	87	0	8
Vessel Physical Damage	1,562	799	105	2	29
Individual Periodic Vendor or Festival Vendor Economic Loss	388	8	3	0	0
Total	374,308	101,609	9,813	256	1,736

Table 5: Gulf of Mexico Oil Spill Payments (millions of US Dollars)

Claims Program	Amount
BP Claims Program	\$395.620
Gulf Coast Claims Facility	\$7,566.549
Court Supervised Settlement Program	\$6,517.795
Total Claims Paid	\$14,479.964

Table 6: API Estimates of Well Control Rule Costs

year	nominal cost	discounted cost (3%)
0	2421	2421.000
1	2800	2718.447
2	3402	3206.711
3	3547	3246.007
4	3589	3188.780
5	3606	3110.567
6	3378	2829.022
7	2753	2238.441
8	3050	2407.698
9	3284	2516.913
10 year total	31830	27883.586
annual average	3183	2788.359

Note: costs reported in millions of US Dollars

Table 7: Impact of Water Depth on Number of Oil Spills

	Poisson		Negative Binomial	
	(1)	(2)	(3)	(4)
Average well depth	0.057^{**}		0.059^{**}	
(100s of feet)	(0.023)		(0.023)	
# wells drilled	0.409^{*}	-0.701^{*}	0.405^{*}	-0.717^{*}
(100s)	(0.443)	(0.412)	(0.455)	(0.418)
# deep water wells drilled		4.803^{**}		4.999^{**}
(100s)		(1.908)		(1.975)
constant	-2.136^{***}	-1.409^{***}	-2.147^{***}	-1.424^{***}
	(0.517)	(0.303)	(0.527)	(0.312)
$\ln(\alpha)$			-0.237	-0.235
			(0.547)	(0.529)
χ^2	7.093	6.577	7.227	6.685

Number of observsations = 276. Robust standard errors in parentheses.
Stars indicate significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure 1: Oil Spills, 1990-2012, by Water Depth.

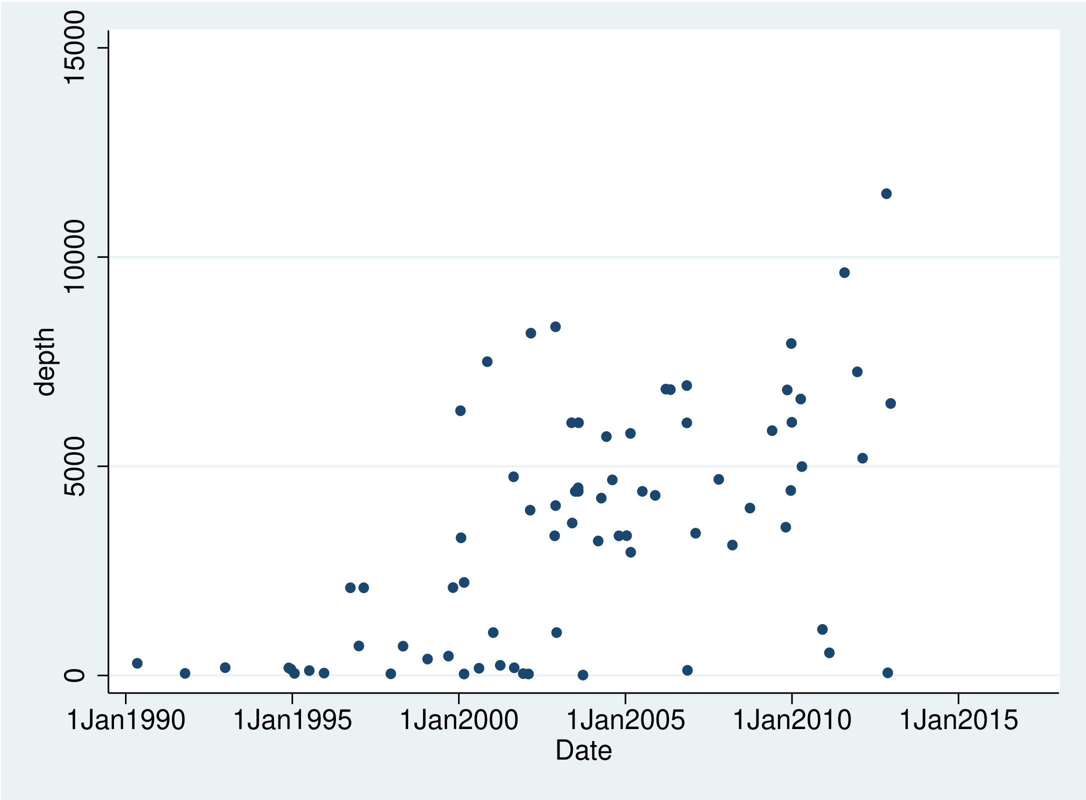

Figure 2: Average Depth and Number of Wells Drilled, 1990-2012.

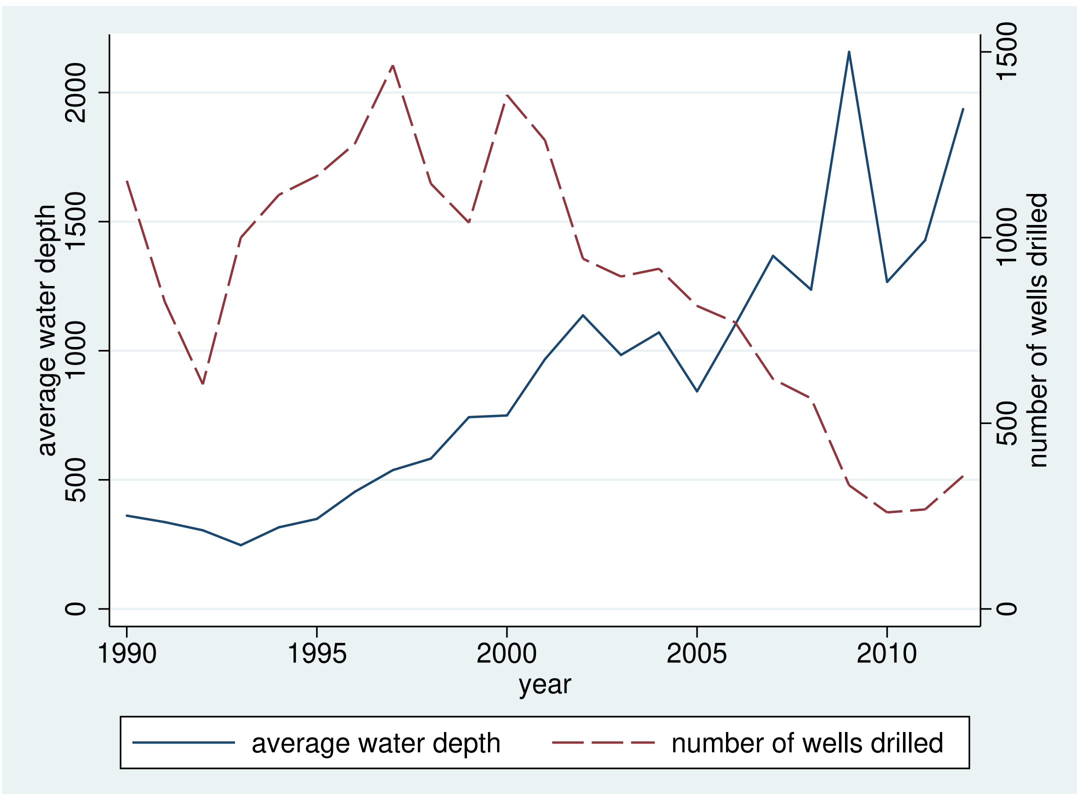

Figure 3: Frequency of Oil Spills: More vs. Less than 1,000 Barrels.

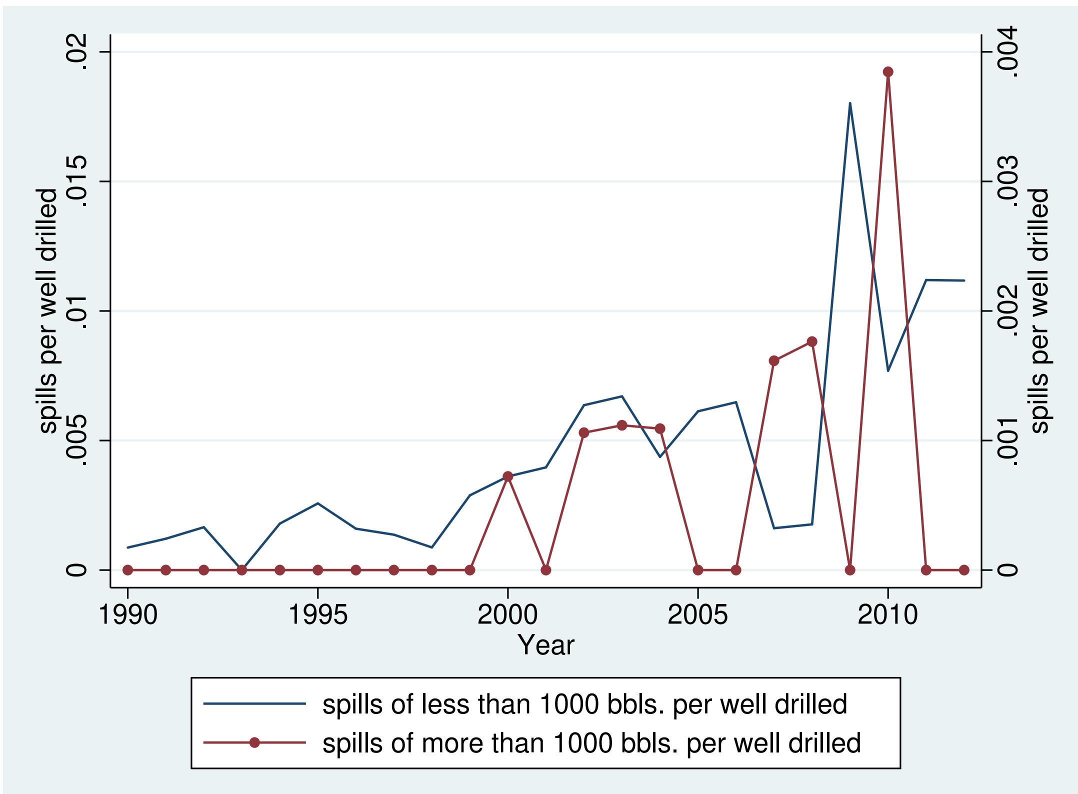

Figure 4: Societal willingness to pay for reductions in the risk of a large oil spill.

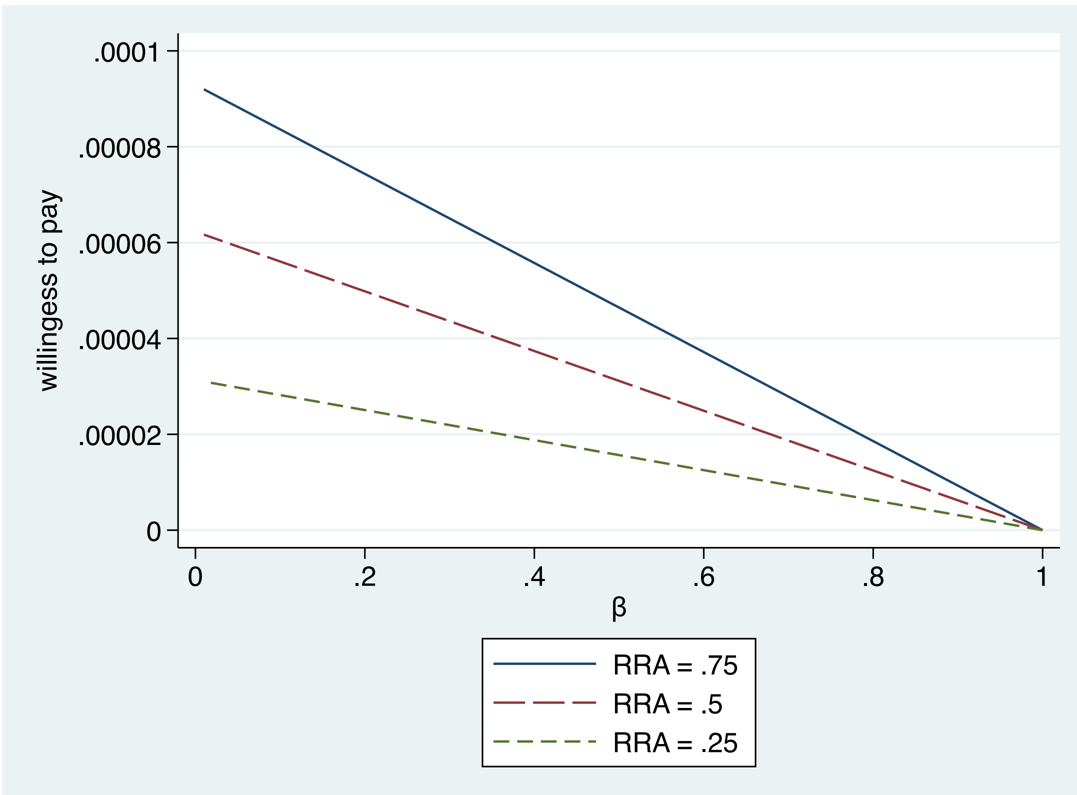

Figure 5: BP/Gulf Coast Claims Facility Payment History.