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Measuring the Impact of the BP *Deepwater Horizon* Oil Spill on Consumer Behavior: Evidence from a Natural Experiment.

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Abstract

A natural experiment setting is exploited to develop a unique dataset of oyster consumer actual and anticipated behavior immediately prior to and following the BP *Deepwater Horizon* oil spill. Using data from a repeat sample of oyster consumers, a pre and post-spill revealed and stated preference model allows both a short and longer-term response to the spill to be investigated. Findings indicate that, as expected, the BP spill had a negative impact on oyster demand in terms of short-run actual behavior, although spill effects show signs of dissipating several months following the spill. However, by accounting for unobserved heterogeneity in the sample, findings further indicate that short and longer-term spill responses differ across consumer groups. For the larger consumer groups, the negative spill effects continue over the longer-term horizon, while other groups are either non-responsive or increase consumption following news of the spill.

Key words: Consumer behavior, BP oil spill, revealed and stated preference, latent class analysis.

JEL codes: Q51, Q10, Q22.

On April 20, 2010, there was an explosion and fire on the BP-licensed drilling rig *Deepwater Horizon* in the Gulf of Mexico. While the *Deepwater Horizon* rig sunk two days later, the sea-floor oil gusher that resulted from the explosion continued to leak until the wellhead was finally capped on July 15, 2010. The *Deepwater Horizon* spill was twenty times the size of the *Exxon Valdez* spill and sent approximately 4.9 million barrels of crude oil into the Gulf of Mexico over a three-month period. The spill had a negative impact on the Gulf of Mexico fishery. Following the spill, the National Oceanic and Atmospheric Association (NOAA) closed recreational and commercial fishing in affected federal waters between the mouth of the Mississippi River and Pensacola Bay, Florida. This closure initially incorporated 6,814 square miles (17,650 km^2) of Gulf waters. By late June, NOAA had increased the area under closure over a dozen times. At its peak, 88,522 square miles, or 37 percent of Federal waters were closed to recreational and commercial fishing in the Gulf.[1]

Due to concerns over potential health-risks associated with consumption of contaminated seafood, the federal government also declared a fisheries disaster for Louisiana, Alabama and Mississippi. Producing almost two-thirds of all oysters consumed in the U.S., oysters harvested from the Gulf of Mexico (eastern oysters) are an economically important commercial fish species for both producers and consumers. For producers, between 2001 and 2010 landings of Gulf oysters ranged from 16 million to 27 million pounds. Ex-vessel revenue ranged from $61 million to $75 million ($2010), accounting for about 10% of total ex-vessel revenue generated by Gulf of Mexico fisheries (personal communication, National Marine Fisheries Service).

With the flow of oil breaching oyster beds, there were serious concerns that the oil could get into the food chain; a concern that was exacerbated by the use of chemical dispersants that

[1] Details of the spill impacts can be retrieved from <
http://www.noaanews.noaa.gov/stories2011/20110419_gulfreopening.html>

were applied to accelerate the dispersal process. Specifically, the use of dispersants can break up the oil into droplets small enough to enter the food chain. Testing found traces of polycyclic aromatic hydrocarbons (PAHs) that are directly linked to oil spills and contain carcinogens in Louisiana coastal waters. PAHs can have serious negative human health effects if they enter the food chain (typically through plankton, finfish, or shellfish) and tests found that levels were 40 times higher than before the spill.[2] Posing an additional potential health risk, researchers also believe that the growth of *Vibrio vulnificus* (*V. vulnificus*) bacteria can be spurred by oil and contaminants from the spill.[3] *V. vulnificus* is a gram-negative bacterium found naturally in coastal waters along the Gulf, Atlantic, and Pacific coasts, although it is most widespread in the warm waters of the Gulf of Mexico. Along with *V. cholera*, *V. vulnificus* is considered to be more lethal than the remainder of the vibrios, inhabiting brackish and salt water, and found in higher concentrations in summer months when coastal waters are warm.[4] Each year in the U.S., there are approximately 100 individuals that become seriously ill (typically by contracting primary septicemia or gastroenteritis) from consuming raw Gulf of Mexico oysters, of which about 35% of those at risk die from the infection (Scallan et al. 2011). Combined, the direct impact from PAHs entering the food chain and indirect effects on *V. vulnificus* growth, may heighten risk perceptions, and influence consumer demand for oysters, as a result of the spill. Following the spill, all Louisiana oyster harvest areas were closed. Over the course of the year following the spill, sections of the fishing closures were incrementally lifted on several occasions. Exactly one year to the day of the spill, NOAA re-opened the final 1,041 square miles of Gulf waters immediately surrounding the *Deepwater Horizon* wellhead.

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[2] <http://www.reuters.com/article/2010/09/30/us-oil-spill-carcinogens-idUSTRE68T6FS20100930>

[3] <http://www.foodsafetynews.com/2010/07/will-oil-eating-bacteria-plague-the-gulf/>

[4] Higher temperature-based concentrations of *V. vulnificus* between May and August is one reason for the common adage among raw oyster consumers to "only eat oysters during the 'R' months."

In general, studies analyzing the effects of contamination incidents or harvesting bans on consumer behavior consistently illustrate that, not surprisingly, news of the incident raises risk perceptions and reduces consumer demand for the product, at least in the short term (Swartz and Strand 1981; Smith, van Ravenswaay, and Thompson 1988; Brown and Schrader 1990; Wessells, Millers, and Brooks 1995). These studies use either market-based data or stated preference methods. Using market data, Swartz and Strand (1981) and Smith, van Ravenswaay, and Thompson (1988) find the post-contamination decline in demand to be short-lived, with the strongest decreases in consumption in the month following the incident but with consumption returning to its previous level two months after the event. The principle constraint of using market data is that examining the effect that news of the event has on consumer behavior requires researchers to create a scaled information variable as a proxy for the provision of media information. The information variable is created in an attempt to account for the total effect of the contamination or harvesting ban incident. However, to what degree these researcher-created variables accurately capture the information effect is debatable. To provide some examples, Wessells, Millers, and Brooks (1995) analyze the effects that news of toxic algae contamination has on mussel demand in Montreal by including a scaled media information variable equal to the weekly number of negative articles appearing in a local newspaper. Swartz and Strand (1981) analyze how news of oyster bed closures in the James River in Virginia due to kepone contamination impact oyster consumer behavior in the Baltimore area. They include an information vector based on the level of newspaper coverage and the likelihood that it negatively influences oyster consumption. Smith, van Ravenswaay, and Thompson (1988) also use an information dummy in their model of sales losses following a milk ban in Hawaii, although they acknowledge potential issues, suggesting that the dummy "is a crude proxy" to capture the information effects, and “it may be more useful to consider more accurate ways of representing diffusion of information about a contamination incident.”

Stated preference methods can avoid the problem of capturing the media information effect by disseminating specific risk information across respondents. The effects of the information treatment on expected consumer behavior can then be isolated. Parsons et al. (2006), Morgan, Huth and Martin (2009), and Morgan et al. (2013) survey consumers and use revealed and stated preference (RP/SP) methods to examine the effects of consumer health-risk information on seafood consumer behavior. They provide respondents with hypothetical health-risk information based on actual media coverage and examine their behavioral responses. Results from these studies all suggest that consumption risk information raises risk perceptions, and causes a decrease in demand. In a study that specifically considers oil spill impacts, Wessells and Anderson (1995) survey 156 Rhode Island households to examine factors affecting seafood consumption behavior and seafood safety perceptions. Using a recursive system of equations that describe the influence of seafood safety perceptions on expected demand, they find that consumers anticipate a decrease in seafood consumption if faced with hypothetical negative information regarding an oil spill and closure of the Naragansett Bay to fishing. However, while stated preference methods provide a means to directly measure the impact of contamination information on behavior, a common drawback is that these analyses are typically confined to examining short-term and arguably heightened consumer reactions to an event as consumers’ consumption changes are elicited immediately following exposure to an information treatment. In this research, due to the timing of the spill, we exploit a natural experiment setting and develop a RP/SP framework that models individuals’ actual and expected oyster consumption behavior over the spill period. The unique dataset and modeling approach enables the impact of the spill on oyster consumers' risk perceptions, and in turn, consumption behavior, to be analyzed in both the short and longer term. We provide a timely contribution to the body of literature examining the impacts of contamination events on consumer behavior, especially after an event of the magnitude of the BP spill. Specifically, we survey oyster consumers on their actual and expected oyster consumption choices in March and April, 2010, collecting the last observation on the morning of the *Deepwater Horizon* explosion. We then re-sample a portion of these respondents after the spill to again elicit actual and anticipated consumption behavior. A pre and post-spill RP/SP model framework is developed to measure oyster consumers' responses to a major spill event, and associated changes in individual and aggregate welfare. Our findings extend any previous research in this area that we are aware of by taking advantage of the natural experiment setting to examine the impacts of the spill on both short-term actual consumption behavior and longer-term anticipated behavior. Results from pre and post-spill RP/SP measures show that, as expected, the spill has a negative impact on short-term actual demand for the average respondent. This creates aggregate welfare losses in the region of $4 million. However, the negative spill effects dissipate over the longer-term horizon as anticipated consumption begins to return toward pre-spill levels.

To provide a deeper analysis into consumers' behavioral responses, we also incorporate unobserved heterogeneity into the RP/SP framework by estimating a latent class (LC) model. The LC model investigates whether actual and expected behavior of different classes of consumer varies due to the spill. Results from a four-class LC model indicate that the two largest classes of consumers respond in the same manner to the spill as the average consumer in the short run. However, for these two groups, the negative spill effects continue into the future and over the time horizon of the study do not show signs of recovering. As such, welfare losses persist. Findings from the smaller consumer groups also suggest heterogeneous behavioral responses. While behavior of one group is insensitive to the spill over both time horizons, findings indicate that the final class of consumer is perhaps less risk averse as the spill increases their oyster demand.

Survey, Sampling, and Study Design

We develop an internet-based survey of oyster consumers (aged 18 and over), sampled from the U.S. Center for Disease Control-designated "case states."[5] These are Florida, Alabama, Mississippi, Louisiana, Texas, and California.[6] The online survey was administered by Online Survey Solutions, Inc. (OSS) and the survey was administered between March and April, 2010. The last observation for Survey 1 was collected on April 20, 2010, the day of the BP *Deepwater Hoizon* explosion, but before any public announcement regarding a spill was made. The purpose of the first survey is to gather data on oyster consumers' attitudes, preferences; awareness and perceptions of oyster consumption health risk; knowledge about oyster consumption health risk; and relevant demographic data. Also, to meet our research objectives of analyzing oyster consumer behavior to existing and new U.S. Food and Drug Administration (FDA) and Interstate Shellfish and Sanitation Conference (ISSC) policies designed to mitigate annual illness incidence from consuming raw Gulf of Mexico oysters, respondents are asked a series of stated preference questions regarding their annual oyster consumption based on current conditions and after being provided with different educational information treatments and information on post-harvest

[5] CDC case states are states in which there are documented cases of *V. vulnificus*-related deaths.
[6] Due to a request from Georgia Sea Grant, we also sampled consumers from that state.

processing (PHP) methods. Usable observations from 1,849 oyster consumers were collected. We now refer to this survey as the pre-spill survey.[7]

By survey design, respondents from the pre-spill survey are first asked about their current annual consumption frequency to generate pre-treatment baseline data for oyster consumption experience (revealed preference). To aid the respondent in determining the annual amount, they are asked how many months in a year they typically consume an oyster meal, and then, in a typical month in which they eat oyster meals, about how many oyster meals do they eat.[8] The survey software then computes the annual number of meals and respondents are offered the opportunity to adjust the number if desired. Responses to this question represent the pre-spill revealed preference annual number of oyster meals consumed (*RP1*). Next, respondents are asked whether, compared to the number of meals they revealed they consume in a typical year, they expected to eat more, less, or the same number of oyster meals next year? Respondents are then prompted to state how many more or less as required (stated preference). In estimation, inclusion of a stated preference count under existing conditions provides a means to control for potential hypothetical bias in individual responses (Whitehead et al. 2008). Responses represent a pre-spill stated preference meal count (*SP1*). Finally, in order to derive an oyster demand curve, respondents are also asked to state whether they would eat more, less, or the same number of meals under both a price increase and a price decrease scenario (while being informed that the price of all other food products remained the same), where the price changes were varied randomly across respondents.[9]

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[7] A more in-depth discussion of the pre-spill survey is detailed in Morgan et al. (2012).
[8] Respondents were informed that oyster meals included any meal in which the main course was oysters, or oysters were an important ingredient in the dish (like gumbo), or meals in which they are an oyster appetizer. Pictures were also displayed to provide examples of oyster meals.
[9] Each respondent receives a price increase of $1, $3, $5, or $7, or a price decrease of either $1, $2, $3, $4.

With the timing of the pre-spill survey and BP spill, we developed a follow-up survey, designed to elicit individuals' attitudes regarding the spill, seafood safety concerns, expectations regarding the length of the oyster harvest ban in Louisiana, and stated preference consumption based on expected ban length. We refer to this as the post-spill survey. The online post-spill survey was again administered by OSS in November/December, 2010 (seven to eight months following the spill). As part of this effort, we re-sampled some of the respondents from the pre-spill Survey 1. In total, the post-spill survey collected 1,087 observations, of which, 504 respondents had also answered the pre-spill survey. In total, there were 382 usable responses from oyster consumers that completed all the pre-spill and post-spill RP/SP elements from both surveys.

In the post-spill survey, we ask respondents the same four RP/SP questions as described in Survey 1. Again we ask respondents about their actual and expected annual oyster meals consumed (which we refer to as *RP2* and *SP2*, respectively) plus stated preference price increase and decrease scenarios. Combined, the pre and post-spill RP/SP questions enable an investigation into the short and longer-term effects of the spill on oyster consumer behavior. In addition, following the spill, a ban on harvesting oysters from Louisiana oyster beds was mandated. At the time of the post-spill survey, the ban remained in place for approximately 50 percent of Louisiana oyster beds. We were interested in examining, not only how a partial ban on oyster harvesting impacts consumer behavior, but to investigate how the length of the existing ban relative to individuals' expectations impacts consumption behavior. To accomplish this, we ask a further SP question under an oyster harvesting ban scenario. Under this scenario respondents are informed that the State of Louisiana Health and Hospitals "CLOSED" several Louisiana shellfish harvest areas to the harvest of oysters and other molluscan shellfish. While some shellfish harvest areas have since reopened, the ban on oyster harvesting from many of Louisiana's shellfish harvest areas currently remains in place. Respondents are then asked how long they expect the ban to last from a list of seven possible durations (scaled from "not much longer" to "more than a year"). Next, respondents are told to imagine that the Louisiana ban on harvesting oysters from affected areas lasts for about another [NUMBER], where [NUMBER] is randomly assigned and varied across respondents from a list of four possible values; namely, "month", "3 months", "6 months", or "9 months". Respondents are then asked:

> "Suppose that the average price of their oyster meals stays the same, compared to the number of oyster meals you previously told us you expect to eat next year, do you think you will eat more, less, or about the same number of oyster meals next year?"
> Again, respondents were then prompted to state how many more or less as required.

Table 1 defines all pre and post-spill RP/SP scenarios plus provides descriptive statistics for meal counts elicited under each scenario. Table 2 provides sample definitions and descriptive statistics for variables used in the analysis for the sample. The majority of respondents were female (53 percent) and Caucasian (79 percent) with an average sample age of 47 years and earning an average household income of $73,500. Less than half of respondents believe that Gulf oysters are safe to eat following the spill. Approximately 68 percent of respondents consume raw oysters and 17 percent are immune-compromised, as they indicated that they have one of the health conditions necessary to be vulnerable to a *V. vulnificus* infection.

The Conceptual Framework

Both pre and post-spill RP/SP data for a model of oyster consumer consumption behavior is collected via an online survey instrument. Pre and post-spill RP data is based on actual annual number of oyster meals consumed. Pre and post-spill SP data is used to stimulate an expected change in oyster meals consumed resulting from price changes and a ban on Louisiana oyster harvesting due to the BP spill. Specifically, SP questions are asked about future meals consumed: (1) under pre-spill existing conditions, (2) with a pre-spill price increase and decrease scenario, (3) under post-spill existing conditions, (4) with a post-spill price increase and decrease scenario, and (5) with a post-spill ban on Louisiana oyster harvesting continuing for another month to 9 months.

As the dependent variable is a nonnegative integer with a high frequency of low meals consumed, a count panel data model is estimated

$$\Pr(x_{it}) = \frac{e^{-\lambda_{it}}\lambda_{it}^{x_{it}}}{x_{it}!}, x_{it} = 0,1,2,\ldots \quad (1)$$

The natural log of the mean number of meals is assumed to be a linear function of prices, socio-demographic indicators, consumption behavior and health characteristics, and a ban scenario scaled variable. To allow for variation across oyster consumers that cannot be explained by the independent variables, we assume that the mean number of meals also depends on a random error, u_i. The RP/SP Poisson demand model is:

$$ln\lambda_{it} = \beta_0 + \beta_1 P_i + \beta_2 y_i + \beta_3 \boldsymbol{s} + \beta_4 \boldsymbol{c}_i + \beta_5 RP1 + \beta_6 SP1 + \beta_7 SP2 + \beta_8 BAN + \mu_i \quad (2)$$

where P is the change in price of an oyster meal; y is income; $\boldsymbol{s}$ is a vector of socio demographic variables; $\boldsymbol{c}$ is a vector of individual consumption and health characteristics; individuals are indexed i = 1, …, 382; and t = 1, …,9 denotes annual oyster meal demand under a pre-spill RP status quo treatment, post-spill RP status quo, pre-spill SP status quo, post-spill SP status quo, pre-spill SP price increase, pre-spill SP price decrease, post-spill SP price increase, post-spill SP price decrease, and a post-spill SP information treatment on a Louisiana oyster harvesting ban in the pseudo-panel data. Dummy variable *BAN* (*BAN* = 1 when $t = 9$) is a demand shift variable for the ban treatment scenario. *SP* = 1 for hypothetical meal data ($t = 3, \ldots, 9$) and 0 for revealed meal data (t = 1 and 2). $\beta_0 - \beta_8$ are coefficients to be estimated in the model. Pooling the data suggests that panel data methods be used to account for differences in variance across sample individuals, i, and scenarios, t. The distribution of meals conditioned on u_i is Poisson with conditional mean and variance, λ_{it}. If $\exp(\lambda_{it})$ is assumed to follow a gamma distribution, then the unconditional meals, x_{it}, follow a negative binomial distribution (Hausman, Hall, and Griliches 1984). The random effects Poisson model imposes positive correlation across the t scenarios (Landry and Liu 2011).

With the semi-log functional form, the baseline economic benefit per annual oyster meals consumed for the representative consumer as measured by average annual per-person consumer surplus (CS) is:

$$\text{CS} = \frac{\hat{x}}{-(\beta_1)} \qquad (3)$$

where $\hat{x}$ is the annual number of predicted meals for the representative oyster consumer and all independent variables are set at sample means (Bockstael and Strand 1987). The short-run change in annual per-person CS as a result of the spill is represented by:

$$CS = \frac{(\hat{x})-(x\prime)}{-(\beta_1)} \tag{4}$$

where $\hat{x}$ and x', represent pre and post-spill actual meal counts. The long-run CS effects due to the spill are estimated in a similar fashion with the appropriate RP/SP meal counts.

We compare results from the standard pooled RP/SP model to a latent class model allowing behavioral responses to the health-risk information treatments to be examined across classes of consumer. Formally, the latent class model is described by an individual consumer that resides in a latent class, *c*. The individual class membership (denoted by C_i^*= 1,…,*n*) is unknown (latent) to the researcher. The underlying utility of individual *i's* consumption *x*, under information treatment *t*, given that the individual belongs to latent class *c*, can be expressed as:

$$U_{ixt} = \beta_c' \boldsymbol{X}_{ixt} + \varepsilon_{ixt} \tag{5}$$

where $\boldsymbol{X}_{ixt}$ is a union of all attributes that appear in all utility functions, β_c' is a class specific parameter vector, and ε_{ixt} indicates the unobserved heterogeneity for individual *i*'s consumption *x*, under information treatment *t*.

For each class, the actual number of annual meals consumed, x_i, is assumed to be drawn from a Poisson distribution. Within each class, the underlying parameters of the Poisson distribution are allowed to vary. Specifically, we assume that:

$$\Pr(y_i^* = m | C_i^* = c) = \frac{\exp(-\lambda_{ic})\lambda_{ic}^m}{m!} \; i = 1, \dots, I: c = 1, \dots, n \qquad (6)$$

where $\lambda_{ic} = \exp(\boldsymbol{X}_i'\beta_c)$ represents the conditional mean number of oyster meals consumed in class c given characteristics $\boldsymbol{X}_i$ and the parameter vector β_c.

Results

Table 3 presents the results from both a random effects Poisson model and a negative binomial latent class model of oyster demand. The dependent variable is the annual number of oyster meals consumed. The model in the first column is the model we refer to as the standard model. It is a standard Poisson model that assumes a homogenous mean influence of the spill and other explanatory variables on annual oyster meal demand. Columns two through five present the findings from a negative binomial panel model that allows for unobserved heterogeneity with respect to actual and expected annual meal counts and other explanatory variables. We refer to this as the LCNB model. We estimated a LCNB model with 2, 3, and 4 classes and then compared two measures of fit first developed by Hurvich and Tsai (1989). We report the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Scarpa, Thiene, and Tempesta (2007) discuss that these statistics help direct the researcher on the number of classes to choose. The four-class specification has the lowest score on both criteria so we report results from this model. It is also worthy to note that the LCNB model has a lower score on both criteria, plus a lower log-likelihood value than the standard model, indicating a better fit for the pre and post-spill data than the standard model. Also reported in Table 3, the four-class model specification allocates 20% of sampled respondents to Class 1, 33% to Class 2, 33% to Class 3, and 14% to Class 4.

Per-person, per-meal and annual per-person consumer surplus measures are presented in Table 4, together with 95% confidence intervals constructed using a bootstrapping procedure (Krinsky and Robb 1986). The procedure generates 10,000 random variables from the distribution of the estimated parameters and generates 10,000 consumer surplus estimates. The estimates are sorted in ascending order and the 95% confidence intervals are found by dropping the bottom and top 2.5% of the estimates.

For the average consumer in the sample, the price coefficient is, as expected, negative and highly statistically significant, so oyster consumer behavior conforms to the law of demand. The price coefficient from the standard model implies a per-person, per-meal consumer surplus estimate of $19.15, or an annual per-person estimate of $427.[10] Based on our estimate of 467,000 Gulf of Mexico oyster consumers, this equates to approximately $199 million in aggregate welfare for Gulf of Mexico oyster consumers.[11] Once we account for unobserved heterogeneity in the sample, the price coefficients in the LCNB model vary across consumers, indicating variation in consumer welfare, across classes. For Class 2, 3, and 4 consumers, per-meal CS estimates are $12.19, $16.45, and $13.70, respectively. Annual mean CS measures are $272, $367, and $305, respectively for the three subgroups. We do not report welfare measures for Class 1 consumers as the price and all RP/SP coefficients are statistically insignificant.

[10] The baseline level for mean annual expected meal counts is 21.9. It should be noted that we consider reduced demand following the spill as a loss in individual welfare, or an avoidance cost, as first posited by Swartz and Strand (1981) in their paper, coincidently also examining the effects of contamination news on oyster demand.

[11] Our estimate of 467,000 Gulf of Mexico oyster consumers is based on average annual landings of 22 million pounds of oysters. With a 100-pound sack containing about 250 oysters and the average oyster meal containing about 6 oysters, this equates to consumers eating about 9.3 million Gulf of Mexico oyster meals annually. Sampled respondents indicate they consume an average of 19.9 meals per year (see Table 2). This implies 467,000 Gulf of Mexico oyster consumers.

Parameter estimates for the RP/SP measures utilize the natural experiment setting to examine the effect of the spill on short-run actual behavior and longer-term expected behavior. We examine consumers' short-run response to the spill in two ways by comparing post-spill actual meal counts (*RP2*) to both pre-spill actual (*RP1*) and pre-spill expected meal counts (*SP1*). First, the coefficient on *RP2* is negative and statistically significant at the 1 percent confidence level, so the actual number of oyster meals consumed by individuals after the spill is below pre-spill actual meal counts. It is worth noting that as all counts are annual, this avoids any potential seasonal effects in oyster consuming behavior, so we attribute any change in actual meals consumed solely to the spill. Also, the coefficient on *RP2* is greater in magnitude than the coefficient on *SP1*, so post-spill actual demand also falls below pre-spill expectations, reaffirming that the spill reduces short run demand.[12] These findings indicate that demand from the average consumer declines significantly in the short run following the spill. Combined these measures imply a loss in per-person, per-meal consumer surplus of between $8.46 and $9.39, or between $4.0 and $4.4 million in aggregate annual welfare.[13]

The LCNB model highlights heterogeneity in the data with regard to short-term actual spill responses. While the Class 1 group of consumers are not responsive to the spill, the two largest groups (Class 2 and 3) behave in line with an average consumer, reducing short run demand in response to news of the spill. Conversely, Class 4 consumers actually increase oyster consumption once news of the spill is disseminated. The Class 4 group response is unexpected, however the coefficients on the socio-demographic indicators reveal some interesting differences in behavior from this smaller group of consumers. They are the only class to consider oyster

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[12] A Wald test (W = -0.202 with probability value = 0.00) indicates that the difference between pre-spill expected meals and post-spill and actual meals (*SP1* and *RP2*) is statistically different from zero.
[13] This can perhaps be viewed as a lower-bound estimate of welfare losses as the second survey was conducted eight months following the spill. As such, four months of the *RP2* counts were consumed prior to the spill.

meals normal, as opposed to inferior, goods, with females and younger consumers more likely to eat more meals, unlike the other classes. While these differences may affect their spill response, other rationales exist. Perhaps this group consists of consumers that do not perceive any negative health effects from the spill and expect harvesting shortages to lead to higher future prices, or that this group is more sympathetic to the oyster industry and is perhaps expressing support for the industry following the spill. Another possibility is that the Class 4 group is generally less risk averse. This notion is perhaps supported by the positive and significant coefficient on the *AT-RISK* parameter. Recall, immune-compromised consumers are vulnerable to morbidity and mortality risk from consuming Gulf oysters due to the potential presence of the *V. vulnificus* bacteria. While at-risk consumers in the other classes all consume fewer oyster meals than non-vulnerable consumers, vulnerable Class 4 consumers consume more meals, suggesting a degree of risk insensitivity.

For longer-term impacts associated with the spill, again two comparisons are important. First, we examine whether the number of oyster meals consumers expect to eat after the spill differs statistically from pre-spill expectations. We compare a restricted model (*SP* = *SP1* + *SP2*) with the standard, unrestricted model that allows pre and post-spill stated preference counts, under existing conditions, to vary. A likelihood ratio test suggests a greater than 95 percent probability that the two models are significantly different, so for the average consumer, expected meal counts elicited after the spill are significantly different to those elicited before the spill. [14] As *SP2* is greater in absolute terms than *SP1*, the spill also has a long-term impact of reducing expected demand. However, by comparing *RP2* and *SP2*, eight months after the spill, it appears that the long-term negative responses to the spill are tempered and demand is beginning to increase with time. That is, we see a rebound in oyster demand as consumers indicate that they

[14] Likelihood ratio test = 2(-11134.2 – (-21105.6)) = 19942.8 with 1 d.f.

anticipate consuming more oyster meals in the future than they did in the few months following the spill.[15] Over time, demand is moving back toward its pre-spill baseline and welfare losses are mitigated. The increase in post-spill expected relative to actual demand increases per-person, per-meal welfare by $2.02, and annual aggregate welfare by $0.9 million.

We also observe long run behavioral differences across subgroups. Again, Class 1 consumers are non-responsive to the spill over a longer-term horizon. For the larger groups (Class 2 and 3), post-spill expected demand remains significantly below pre-spill expectations, so the spill continues to negatively impact these groups. However, for these two groups post-spill expected relative to actual behavior differs from the typical consumer in the sample. Specifically, for both classes, *RP2* and *SP2* estimates are not statistically different from zero so we do not observe any long-term rebound in demand. Instead, the short-term fall in demand persists over a longer-term horizon with no statistically significant increases in welfare. Finally, for the small and potentially risk loving Class 4 group, post-spill expected demand is also not different from the actual response so the positive spill impacts continue into the future.

Finally, at the time of the survey a partial ban on harvesting oysters was in place for Louisiana oyster beds. The final SP question in the post-spill survey asks respondents to state any change in expected behavior in response to a randomly assigned continuation of the ban. In estimation we code the ban variable (*BAN_DIFF*) as the difference between individuals' expected length of the ban (*BAN_LENGTH*) and the stated length of the ban (*BAN*). As such, *BAN_DIFF* captures the difference between individuals' expected and actual ban length. The negative and highly significant coefficient on the *BAN_DIFF* variable indicates that the longer the period between respondents' expectations regarding the length of the ban and its actual

[15] A Wald test (W = 0.05 with probability value = 0.00) indicates that the difference between post-spill actual (RP2) and expected (SP2) meals is statistically different from zero.

duration significantly reduces oyster consumption. In the literature, the effect of a harvesting ban is typically captured by examining how consumption behavior changes to news of a ban at a single point in time (Swartz and Strand 1981; Smith, van Ravenswaay, and Thompson 1988; Wessells, Miller, and Brooks 1995). We also ran the model using a simple dummy variable equal to one when stated preference counts were elicited under the ban scenario. The ban coefficient was not statistically significant. Combined, these findings provide some additional insight into consumers' reaction to a harvesting ban by illustrating that consumers' responses to a ban can't necessarily be represented by a binary variable (i.e., they are only responsive to a ban or no ban scenario), but rather, that the length of the ban relative to expectations can be influential.

Conclusions

This research takes advantage of a unique dataset of oyster consumer behavior in a natural experiment setting to analyze the impact of the BP *Deepwater Horizon* oil spill on consumer demand. Using a repeat sample of oyster consumer behavior immediately before and approximately eight months following the spill, we develop a standard RP/SP model that extends the findings of other research in this area by enabling both the short-term and longer-term impacts of the spill on oyster demand to be analyzed.

Results show that, as expected, the BP spill significantly reduces demand for oysters in the months following the spill. This short-term reaction is in line with several other studies looking at health scare demand effects (Swartz and Strand 1981; Smith, van Ravenswaay, and Thompson 1988; Brown and Schrader 1990; Parsons et al. 2006). However, while studies using market-based data typically demonstrate that decreases in demand return to their baseline level after one to two months, our results indicate that eight months after the spill, demand remains below pre-spill levels so welfare losses persist. Further, while studies using stated preference methods constrain demand impacts and welfare measures to one point in time following the event, the natural experiment enables an investigation of the effects of the spill on expected behavior over a longer-term horizon. For the average respondent, eight months after the spill, while expected demand remains below pre-spill levels, the negative spill effects dissipate and demand begins to move back toward its pre-spill baseline level.

While the standard RP/SP model assumes a homogenous mean influence of the spill and other explanatory variables across sampled oyster consumers, we also incorporate unobserved heterogeneity into the RP/SP framework by estimating a latent class model. The LC model provides a deeper analysis into consumers' behavioral responses to the spill by investigating whether the short and longer-term behavioral impacts vary across classes of consumer. In a four-class LC model, results show that for the largest groups of consumers, short-term responses to the spill are in line with those of the average consumer. However, for both groups, time does not mitigate their response behavior as they anticipate continued reductions in demand in line with their actual response. As such, accounting for heterogeneity highlights that the decrease in consumer surplus as a result of the spill for many consumers persists into the future. Finally, while consumption behavior from one group of consumers is not seemingly sensitive to the spill, short and longer-term oyster meal demand from another group actually increases after the event. We reconcile this result by suggesting that this group perhaps exhibits less risk averse behavior, a notion that is supported by at-risk consumers in the group consuming more oyster meals.

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Table 1. Pre and Post-Spill RP/SP Scenarios and Meal Count Statistics

SP Scenario	Description	Mean Meal Count	Standard Deviation
Pre-Spill Survey			
RP1	Observed annual number of oyster meals consumed	21.9	45.8
SP1	Expected annual number of oyster meals consumed	22.3	46.4
SP1 Price Increase	Expected annual number of oyster meals consumed with price increase	18.6	41.6
SP1 Price Decrease	Expected annual number of oyster meals consumed with price decrease	25.1	49.1
Post-Spill Survey			
RP2	Observed annual number of oyster meals consumed	17.5	38.9
SP2	Expected annual number of oyster meals consumed	18.3	42.3
SP2 Price Increase	Expected annual number of oyster meals consumed with price increase	16.7	43.3
SP2 Price Decrease	Expected annual number of oyster meals consumed with price decrease	20.6	44.4
SP2 Ban	Expected annual number of oyster meals consumed with 1, 3, 6, or 9 month ban	18.3	43.1

Table 2. Descriptive Statistics

Variable	Description	Mean	Std. Dev.	Min	Max
Price	Price of oyster meal				
Quantity	Average annual oyster meals consumed	19.92	43.99	0.00	380.00
Age	Age of respondent	47.46	17.76	18.00	89.00
Gender	Respondent is male (=1)	0.47	0.50	0.00	1.00
Race	Respondent is Caucasian (=1)	0.79	0.41	0.00	1.00
Inc	Household income of respondent ($thousands)	73.51	38.39	8.00	150.00
Rp1	Revealed Preference Question from the Pre-spill Survey (=1)	0.11	0.31	0.00	1.00
Rp2	Revealed Preference Question from the Post-spill Survey 1 (=1)	0.11	0.31	0.00	1.00
Sp1	Stated Preference Question from the Pre-spill Survey (=1)	0.33	0.47	0.00	1.00
Sp2	Stated Preference Question from the Post-spill Survey 1 (=1)	0.44	0.50	0.00	1.00
Raw	Consumes Raw Oysters (=1)	0.68	0.47	0.00	1.00
Ban_Length	How much longer respondents expect ban to last (“1=Not much longer”; “2=About a month”; “3= About 3 months”; “4=About 6 months”; “5=About 9 months”; “6=About a year”; “7=More than a year”)	4.86	2.05	1.00	7.00
Ban	Stated remaining length of Louisiana Harvesting Ban (“1=About a month”; “2=About 3 months”; “3=About 6 months”; “4=About 9 months”)	2.41	1.16	1.00	4.00
Ban_Diff	Difference between BAN_LENGTH and BAN	1.45	2.42	-4.00	5.00
At-risk	Consumer is vulnerable to *V. vulnificus* infection (=1)	0.17	0.38	0.00	1.00

Table 3. Standard Random Effects Poisson RP/SP Model and Latent Class Binomial Model

Variable	Random Effects Poisson Standard Model	Latent Class Negative Binomial Model			
		Latent Class 1	Latent Class 2	Latent Class 3	Latent Class 4
Constant	2.764*** (0.239)	4.358***(0.482)	0.908***(0.100)	2.003***(0.118)	1.64***(0.261)
Price	-0.052***(0.001)	-0.048(0.060)	-0.082***(0.010)	-0.061***(0.010)	-0.073***(0.017)
Inc	-0.002** (0.001)	-0.006***(0.001)	-0.003***(0.000)	-0.000*(0.000)	0.036***(0.001)
Male	0.388***(0.091)	0.174***(0.054)	0.562***(0.022)	0.490***(0.021)	-0.063***(0.037)
Age	-0.003(0.004)	-0.003(0.002)	0.003***(0.001)	0.004***(0.001)	-0.047***(0.001)
Rp2	-0.222***(0.008)	-0.374(0.582)	-0.304**(0.149)	-0.360**(0.167)	0.534*(0.323)
Sp1	-0.020**(0.009)	-0.039(0.625)	-0.050(0.122)	-0.035(0.156)	-0.020(0.375)
Sp2	-0.170***(0.007)	-0.245(0.475)	-0.300***(0.094)	-0.389***(0.114)	0.537*(0.277)
Raw	0.645***(0.110)	0.543***(0.086)	0.413***(0.029)	0.567***(0.021)	-0.442***(0.045)
At-risk	-0.449***(0.155)	-0.524***(0.100)	-0.066**(0.028)	-0.241***(0.027)	2.136***(0.055)
Ban_Diff	-0.022***(0.001)	-0.050(0.033)	-0.035(0.032)	-0.007(0.022)	-0.039(0.038)
Alpha	1.162	0.967	15.659	5.297	9.782
Sample Size	382	382	382	382	382
Periods	9	9	9	9	9
Class Probabilities		0.197	0.331	0.333	0.140
AIC	42215.6	22370.7			
BIC	21163.6	11341.8			
Log Likelihood	-21105.6	-11134.2			

Note: Standard errors are in parentheses.
*Significance at the 10% level; ** Significance at the 5% level; *** Significance at the 1% level.
AIC (Akaike Information Criterion) = -2(LLB-*P*)
BIC (Bayesian Information Criterion) = -LLB + [(*P*/2)*ln(N)]

Table 4. Consumer Surplus Estimates

Panel Model Specification	Mean CS per Meal	Mean Annual CS	Change in Mean Annual CS			
			RP2-RP1	RP2-SP1	SP2-SP1	SP2-RP2
Random Effects Poisson	$19.15 ($18.62, $19.71)	$427.21 ($415.44, $439.62)	-$9.39 (-$9.66, -$9.14)	-$8.46 (-$8.70, -$8.23)	-$6.44 (-$6.63, -$6.26)	$2.02 ($1.96, $2.07)
LC Negative Binomial Model:						
Class 1	N/A	N/A	N/A	N/A	N/A	N/A
Class 2	$12.19 ($9.41, $14.98)	$272.04 ($209.90, $334.19)	-$0.49 (-$0.59, -$0.38)	-$0.40 (-$0.49, -$0.31)	-$0.39 (-$0.48, -$0.30)	$0.01 ($0.01, $0.01)
Class 3	$16.45 ($11.32, $21.59)	$366.91 ($252.46 $481.35)	-$3.15 (-$4.13, -$2.17)	-$2.79 (-$3.66, -$1.92)	-$3.00 (-$3.93, -$2.06)	-$0.21 (-$0.27, -$0.14)
Class 4	$13.70 ($7.30, $20.10)	$305.43 ($162.71, $448.15)	$4.37 ($2.33, $6.42)	$4.50 ($2.39, $6.60)	$4.53 ($2.41, $6.64)	$0.03 ($0.02, $0.05)