

The Value of Statistical Life: Pursuing the Deadliest Catch

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Abstract

Observed tradeoffs between monetary returns and fatality risk identify estimates of the value of a statistical life (VSL), which inform public policy and quantify preferences for environmental quality, health and safety. To date, few investigations have estimated the VSL associated with tradeoffs between returns from natural resource extraction activities and the fatality risks they involve. Understanding these tradeoffs (and the VSL that they imply) may be used to inform resource management policy and safety regulations, as well as our general understanding of the value of life. By modeling a commercial fishing captain's choice to fish or not, conditional on the observed risk, this research investigates these topics from data on the Alaskan red king crab fishery. Using weather conditions and policy variables as instruments, our estimates of the VSL range from \$4.6M to \$4.9M (depending on the modeling assumption) and are robust to the incorporation of heterogeneous preferences.

Keywords: value of statistical life (VSL), discrete choice, Alaskan crab fisheries.

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I. Introduction

Society often faces choices that involve tradeoffs between physical risk and pecuniary returns, and our decisions reveal our willingness to trade money for the risk of physical harm (Ashenfelter 2006).¹ "The ratio of the wealth we are willing to accept in exchange for a small change in the probability of a fatality is expressed in units of 'dollars per death,' or the dollar value of a fatality. It is for this reason that this tradeoff is often called the value of a 'statistical' life" (Ashenfelter 2006, pC10). To date, little attention has been paid to the empirical investigation of the value of a statistical life (VSL) in high-risk natural resource extraction industries. This research investigates this topic using a unique data set on fishing behavior in the Alaskan crab fisheries, recently popularized as "The Deadliest Catch," in a period during which two exogenous policy changes have altered the risks within the fishery.

In 2006 commercial fishing became the riskiest occupation in the United States. According to the Bureau of Labor Statistics (BLS), the fatality rate for fishermen was 141.7/100,000 workers, which is substantially greater than the national average of 3.9/100,000 workers (BLS 2006). Commercial fishing risk is a direct function of the common-pool nature of the resource which often generates a "race for fish" within fisheries. That is, if a fishery is managed with a fishery-wide total allowable catch (TAC), it creates incentives for fishermen to fish as quickly as possible before the TAC is reached and the fishery is closed for the season. When fisheries are managed in this way, the race may generate risky behavior on the part of the participants, and we typically observe rent dissipation and excess capacity within the fishery relative to the socially optimal level (Cheung 1970; Gordon 1954; Smith 1968, 1969). Although many fisheries can be characterized as a regulated open-access fishery (Homans and Wilen 1997) because they possess a fishery wide total allowable catch (TAC) and licenses that may not be obtainable to all (e.g., license limitation program), rent dissipation is still a dominate feature as fishermen "race for fish" generating a "tragedy of the commons" (Hardin 1968).

The use of property rights to mitigate the tragedy of the commons has proven successful in a number of different natural resource environments (Hannesson 2004; Libecap 2006; Neher et al. 1989). Aside from increasing economic efficiency, property rights substantially reduce the incentive to race. If such behavior is positively correlated with risk, the creation of property rights in fisheries may reduce the inherent risks within the fishery.² With mitigation of these risks in mind, two policy changes in the Alaskan crab fisheries have been recently enacted: 1) the United States Coast Guard (USCG) Pre-Season Boarding Program and 2) the transition to property rights management under the Bering Sea and Aleutian

¹ The theoretical foundation for the risk-wealth trade off and the Hicksian compensation variation were initially derived by Jones-Lee (1974).

² Within the Alaskan crab fisheries it is possible that risks may have increased with the adoption of property rights as vessels restructured their capital inputs (i.e., carrying more crab pots) to accommodate the larger vessel-specific annual catch rates. However, determining the degree to which changes in capital impacted vessel-specific risk is beyond the scope of this research.

Island (BSAI) Crab Rationalization Program (BCRP). These programs affect behavior and risk in the Alaskan red king crab fishery and are, hence, sources of exogenous variability which we use as instruments to identify and estimate an estimate of the VSL. We also employ daily variation in weather conditions to the same end. Our approach is in the spirit of Ashenfelter and Greenstone (2004), but our particular data set possess features that make it ideally suited for such an analysis and that allow us to investigate some additional concepts related to the VSL. These issues are discussed throughout the paper.

Valuing health and life as a commodity can be troubling because "we can not produce life years directly or buy them in any market. Goods that can not be produced or sold often become priceless through a natural process that leads to independent utility considerations, great concerns for equity, probing discussions of obligations to the future, and assertions that these goods shall not be allocated through the market" (Fuchs and Zeckhauser 1987, p267). Therefore, the only way the value of life can be estimated is using indirect methods. Viscusi (1993) outlines three indirect methods that can be used to estimate the VSL: 1) survey methods, 2) risk trade-offs inside of the labor market, and 3) risk trade-offs outside the labor market. Survey methods allow researchers to consider a broad spectrum of risk profiles and not just those observed within the environment or labor markets. These methods have been used to investigate the mortality risks associated with pesticide use (Evans and Viscusi 1991; Viscusi et al. 1987), respiratory ailments (Viscusi et al. 1991; Krupnick and Cropper 1992), the effect of age on the VSL (Krupnick 2007), and traffic safety (Hultkrantz 2006), to cite a few. Risk trade-offs in the labor market are traditionally investigated using hedonic wage decomposition models (Rosen 1986; Thaler and Rosen 1976), which regress observed wages on the work related fatality rate with additional control variables for job- and agent-specific characteristics. Hedonic wage decomposition models have been used extensively in the literature; Viscusi and Aldy (2003) cite over 60 different studies that have utilized this method to estimate the VSL. However, there are a number of empirical issues that may bias the VSL estimates within hedonic wage decomposition models. The three most commonly cited are measurement error, omitted variable bias, and the endogeneity of fatality risk (Black and Kniesner 2003; Ashenfelter and Greenstone 2004; Ashenfelter 2006; Kniesner et al. 2006). Due to these shortcomings, this research uses observed non-labor market risk tradeoffs to estimate the VSL.

Measuring the implied VSL outside of the labor market uses the theory of consumer behavior and observed decisions to investigate individuals' money-risk tradeoffs. The earliest investigations focused on the implied VSL resulting from highway speeding (Ghosh et al. 1975) and the use of seat belts (Blomquist 1979). Since then, there have been investigations into: revealed willingness to pay to avoid hazardous waste sites and pollution using property values (Gayer et al. 2000; Portney 1981), automobile accidents using data on new automobile prices (Atkinson and Halverson 1990), and vehicle safety and fuel economy standards (Dreyfus and Viscusi 1995). The primary difference between studies based on

the non-labor market data and labor market data is that in the former the implied risk-money trade-off the consumer faces is directly observed whereas in the later it is decomposed into a risk-wage premium. Therefore, our approach is based on non-labor market data.

Our approach, based on the captain's decision to fish or not on a given day, estimates their marginal rate of substitution (MRS) for fatality risk and economic reward, which is converted to a VSL by multiplying the MRS by the ratio of observed revenues to fatality risk faced by each vessel. We then calculate an average VSL for the fishery. This is similar to the approach of Ashenfelter and Greenstone (2004) who examine the adoption of higher speed limits on rural interstate highways. We estimate our model using data from the Alaskan red king crab fishery over the years 1997-2007. Furthermore, we correct for three important econometric issues which may bias VSL estimates in general: the endogeneity of risk, sample selection (Ashenfelter 2006) and heterogeneity in decision agents (Shogren and Stamland 2002). To control for the endogeneity of risk we employ the two policy changes variables and contemporaneous weather conditions as instruments for daily fatality risks. Given that our estimates of the VSL are only observed for those fishermen who decide to fish on a given day, our estimates of the VSL are subject to sample selection bias and represent an upper bound on the true VSL. To correct for this we conduct a two-stage Heckman sample selection model in the spirit of Ashenfelter and Greenstone (2004) and Ashenfelter (2006) to estimate the true underlying VSL in each fishery. Finally to account for heterogeneity in the decision agent's ability to cope with the inherent risks in the fishery as well as their earnings potential, we estimate a finite mixture model using vessel-specific information to define their vessel type.

Our empirical analysis yields VSL estimates that lie between \$4.6M and \$4.9M, depending on the model estimated. Our results are also robust to the modeling of heterogeneous risk-return tradeoffs. In the following section we provide a general discussion of Alaskan crab fisheries, introduce our data, and provide a descriptive discussion of how policy changes have effected risk, revenues, capital utilization, and crew sizes in the fisheries. Section III outlines our modeling approach and discusses our VSL results with and without heterogeneous vessel behavior. Finally, Section IV summarizes and suggest some additional avenues for research in this area.

II. Fishery and Data Description

With their high fatality rates, the Alaskan crab fisheries have long been recognized as one of the riskiest occupations. For the most part this is due to the seasons during which these fisheries are executed (late fall for red king crab). Fishermen battle adverse seas and inclement weather to harvest crab. During the time period studied (1997-2007) there were two policies enacted which changed the inherent risks within the Alaskan crab fisheries: The USCG Pre-Season Boarding Program and the BSAI Crab Rationalization

Program (BCRP).³ The first policy change occurred in October of 1999 and it required each crabbing vessel to be boarded (by the Coast Guard) prior to the fishing season, to assess vessel safety and stability (unstable vessels can tip and loose crew or completely capsize). Furthermore, each vessel has to receive a Dockside Exam Decal from the USCG before it is issued a fishing license and allowed to fish in the crab fisheries in each season.⁴ The second program began in October 2005, when the crab fisheries shifted from a limited-entry common-pool fishery to a rights-based fishery in which individual transferable quotas were allocated based on historic catch levels. Our *a priori* expectations regarding the impacts of these policies is that they both affected the risks present in the fishery (holding weather constant). The following section is a brief discussion of the Alaskan crab fisheries and these policies. Our purpose is not to evaluate the effectiveness of these programs in mitigating risk in the fishery. Our purpose is simply to argue that these programs are valid instruments for fatality risk in estimating the VSL.

Fatality rates in the Alaskan crab fisheries have historically been among the highest recorded for any fishery across the globe. Figure 1 plots the annual fatality rates per a 100,000 workers for all of Alaska and for Alaskan crab fisheries over the years 1990-2007 with vertical lines indicating the timing of the USCG Pre-Season Boarding Program and the BCRP.⁵ Prior to the inception of these programs, fatality rates were nearly five-times the average fatality rate in all of Alaska (the "overall" rate includes crab fatalities). Following these programs fatality rates dropped by nearly two-thirds and the annual crab fatality rates fell more in line with the average fatality rates for all Alaskan fisheries. Thus, these programs seem to have affected risk in the fishery and are excellent sources of exogenous variability. Just prior to the inception of the BCRP, the fatality rates increased substantially within the Alaskan crab fisheries, but this is primarily due to one event. On January 15, 2005 (opening day of the last season before rationalization for the snow/tanner crab fishery) the fishing vessel "Big Valley" sank and five crew members perished in the Bering Sea. This vessel left port *before* being inspected under the USCG Pre-Season Boarding Program and if removed from the data set (indicated by the "Big Valley" dashed line) it substantially reduces the fatality rate, which is still nearly three times the fatality rate for all Alaskan fisheries.

In 2005 the BCRP was launched. Under this program a quota allocation program was implemented with quota being divided among individual eligible harvesters, processors, captains, and

³ Prior to the time period studied, the Commercial Vessel Safety Act was passed in 1988, which established the initial safety requirements for commercial fishing vessels (Sorum 2003). However, given that this did not occur during the time period studied we have elected to not discuss this policy in detail.

⁴ We would like to thank Jennifer Lincoln of NIOSH, Alaska Field Station and Charlie Medlicott from the United States Coast Guard, Dutch Harbor for providing this information on the USCG Pre-Season Boarding Operations.

⁵ Source data used in figure 1 was obtained from Jennifer Lincoln at NIOSH, Alaska Field Station.

local communities⁶. Eligible harvesters and captains received individual transferable quotas (ITQs) which awarded them a fraction of the seasonal total allowable catch (TAC) and processors received individual processor quota (IPQ) which awarded them the rights to process a given percentage of the TAC. The final group allocated quota were the local communities who received community development quota (CDQ) which consisted of approximately 10% of the seasonal TAC (NOAA 2007).⁷ The allocation of both ITQs and IPQs was enacted in an attempt to address concerns over the market power that either the processors or harvesters might possess if all the quota were allocated to only one of these groups (Anderson 1991; Clark and Munroe 1980; Matulich et al. 1996; Matulich and Sever 1999). The BCRP allocated quota shares to all crab fisheries in the BSAI. In each of the sub-fisheries fishermen formed harvester cooperatives to aggregate ITQs aboard vessels and to allocate the harvesting decisions among the participating vessels within the cooperative in the post-BCRP period. This research will focus on the fall season beginning in mid-October. In the fall season the target species is king crab (*Paralithodes camtschaticus* and *P. playpus*), dominated primarily by red king crab (*Paralithodes camtschaticus*).

The formation of cooperatives facilitated the reduction in physical capital employed within the fishery, which had accrued to a high level in the "race for fish" era (prior to the BCRP), and it had a dramatic effect on both the number of active fishing vessels and the length of the fishing season. Figure 2 shows the number of vessels participating in the red king crab fishery by year, and the days fished each year. As is evident in the figure, season length (days fished) and the number of vessels fishing are inversely related, which is precisely what would be expected given the prevailing fishery conditions prior to rationalization. Following the inception of the BCRP (post-2004) the number of vessels (the first higher then lower curve) dramatically decreased in both fisheries, while season length increased (the first lower then higher curve). Although the number of vessels dramatically decreased following the BCRP, a direct result of the cooperatives, this does not imply that the total amount of fishing effort fell. In raw numbers the number of crew members and captains fishing fell dramatically but when controlling for the length of the season the full-time equivalence of effort remained relatively stable.

Figure 3 shows the total full-time equivalence (FTE) employment rates by year. Given that the season lengths was very short prior to rationalization (due to the "race") and that fishermen are exposed to risk the entire time they are on board the vessel, we constructed our FTE measure as the total number of days fished for each vessel times 24 hours times the number of crew members divided by the normal

⁶ Select rural communities also earned the right to purchase processor quota to prevent processing jobs from leaving their communities.

⁷ Given the small percentage allocated as CDQ as well as the seasonal execution periods of CDQ, we have elected to not include fishing trips which harvested CDQ within our post-BCRP period.

annual work hours for non-seasonal jobs (2000 hrs; 40 hrs./wk multiplied by 50 weeks year).⁸ This construction is the fatality risk measure commonly employed in the labor literature. The trends in FTEs in Figure 3 suggest that the number of FTEs dropped dramatically in 2000. This time period was characterized by a large reduction in the total allowable catch (TAC) within the fishery which in turn led to fewer fishing days and a reduction in FTEs. For instance, in the red king crab fishery the catch fell 30.13% from 1999 to 2000 (NPFMC 2006). Since 2000, the annual landings (catch) in the red king crab fishery have increased, causing a rebound in the FTEs (NPFMC 2006). Controlling for these conditions, the FTEs have remained relatively constant over the past ten years, indicating that the BCRP has not dramatically reduced the level of human capital employed. The primary effect has been a reduction in the both the number of vessels (physical capital) and individuals employed, but an increase in the utilization and duration of employment for the remaining vessels and crew.

One of the arguments for implementing the BCRP was that it would increase the safety of fishermen by eliminating the "race for fish" that prevailed in this fishery (NOAA 2006).⁹ The safety argument hinges¹⁰ on the fact that weather-related vessel instability is the leading cause of vessel accidents and death within the Alaskan crab fishery (Lincoln and Conway 1999; Lucas and Lincoln 2007) and that fisherman could now afford to elect to not fish on high-risk days (since their catches are now secured through property rights). Under the BCRP, captains may be more inclined to wait for good fishing weather because they are guaranteed a pre-specified quantity of crab, their ITQ. This would tend to reduce the number of tipping and capsized vessels and improve the on-deck work environment, preventing individuals from being swept overboard, and the risk of death and injury within the fishery.¹¹ However, it is possible that the program would generate a fleet restructuring (see Figure 2) and concentration of quota (and thus fishing pots) aboard vessels that may generate a new suite of risks resulting in an unpredictable net change in risk (Springer 2006). In addition, delivery contracts between

⁸ Within the red king crab fishery there are two types of vessels that participate with the fishery that are defined by their size, greater than or less than 60 feet. Because we do not perfectly observe the number of crew members on board the vessel for all data points we assume that vessels less than 60 feet have 4 people on board the vessel and vessels greater than 60 feet have 6 people on board.

⁹ The objectives of the BSAI Crab Rationalization Program are outlined on the National Marine Fisheries Service's website. The link is <http://www.fakr.noaa.gov/sustainablefisheries/crab/rat/progfaq.htm#wicr>.

¹⁰ Another safety-related argument is that crew members may no longer have to fish around the clock as they had to do to compete in a race-for-fish scenario, which creates extreme fatigue and increase the likelihood of accidents. However, as we discuss later, the reduction in crew fatigue and fishing pace has yet to fully materialize. This is likely due to a continued desire to minimize days at sea (which are costly), increased catch and quota levels by the vessels that continue to fish, and persistence of the work ethic of individuals who have been historically employed largely because of their ability to work fast for long periods of time.

¹¹ Roughly 27% of the fatalities that occurred within the Alaskan crab fisheries are a result of being swept overboard.

vessels and processing plants still exist and may pressure a captain to catch a pre-specified delivery quantity by a certain date (effectively a race for fish).¹²

To conduct this analysis we use data from a number of sources. The vessel behavior data were obtained from the National Marine Fisheries Service and contains the vessel fish ticket data for all vessels which participated within the red king crab fishery for the years 1996-2007.¹³ The fish ticket contains information on the date a vessel left port to begin fishing, the date they returned to offload their catch, the port at which they landed their catch, the amount landed, and the gross revenues earned on the trip. To obtain information on the vessel's physical capital structure (i.e., vessel length, net-tonnage, horsepower, fuel, hold capacity etc.) we collected data from the state vessel registration files. The fatality rate data were obtained from the National Institute of Occupational Safety and Health, Alaska Field Station and indicates the date the fatality occurred, the location within the BSAI, the cause of the fatality, and the vessel on which the fatality occurred. This information is used to construct fishery-specific daily moving averages of the fatality rate using one-year moving averages.¹⁴

Table 1 contains descriptive statistics for the red king crab fishery broken down by pre- and post-rationalization (BCRP) periods.¹⁵ Across both pre- and post-rationalization periods, the mean revenues within the red king crab fishery are roughly \$93,000. The average trip length for the red king crab fishery varies depending on whether or not it is a pre- or post-rationalization period. The shortened average trip length observed in the red king crab fishery is primarily due to the temporal constraint imposed by the shortened season, whereas the averages observed in other time periods reflect the capital limitations (e.g., filling the live hold, described below) of the vessels participating in the fishery. Mean trip length illustrates another pre-rationalization timing issue, the length of time a vessel is moored waiting to offload their catch. The maximum reported trip lengths are longer than the actual fishery openings and this is due to boats being backlogged at port at the end of the season waiting to offload their catch. Crab can live for an extended period of time in the live holds, and vessels often wait at port to offload. However, should the vessels wait too long, crab will begin to die and fishermen will incur a "dead-loss" which can substantially reduce their trip revenues. Because waiting at the dock will directly influence the trip revenues, but not fatality risk exposure, we truncate the trip length for all trip tickets that report landings

¹² We do not have information on delivery contracts because this information is retained by each individual processor and they are not required to report their delivery contracts to the managing body.

¹³ Data for 1996 was used to initiate the data used in the analysis and we can not use data prior to 1996 because the red king crab fishery was closed in 1994 and 1995.

¹⁴ Alternative moving averages were investigated as well (2-year and 3-year) which generated similar profiles of risk. Because of this, as well as our desire to use as many years of data as possible prior to the USCG Pre-Season Boarding Program, we elected to use a 1-year moving average with data from 1996 used to initiate the 1997 values.

¹⁵ We do not break down the descriptive statistics into pre- and post-USCG Pre-Season Boarding Program because this policy did not have any effect on the capital structure or season length.

two days beyond a fishery closure to account for the time fishermen may spend getting back to port if they are on the fishing grounds when the closure occurs.

Another notable phenomenon in Table 1 is that fixed capital structure is heterogeneous. Vessel length, horsepower, and net-tonnage vary substantially across the fleet. However, the most notable and production-relevant form of heterogeneity is the vessel hold capacity (reflecting the volume of the tanks in which live crab are stored), which possesses a higher standard deviation than its mean in all cases. This heterogeneity will be accounted for in the empirical model to help explain the intra-fleet differences in revenues. Comparing the capital structure between pre- and post-rationalization periods, a number of interesting changes occurred. In the red king crab fishery there was an increase in the mean hold capacity in the post-rationalization era, indicating that vessels which had lower live storage capacities were less likely to be fished by the cooperative.

Another meaningful pre- and post-rationalization change in Table 1 is in landings per vessel (Lbs Harvested), expressed in annual pounds of crab delivered to processors. Given that quota was individually allocated to vessels that then formed cooperatives for the execution of the fishery, many of the vessels in the cooperatives fished for more than their quota allocation (while other vessels sat idle and were paid royalties for their quota). Calculating the total landings for each active vessel in the fleet following the BCRP, we see a fair degree of heterogeneity in catch volume. However, the statistics do show that (for the most part) vessels participating in these fisheries substantially increased their landings by several orders of magnitude after rationalization. To investigate this further we calculated the ratio of each vessel's pre-rationalization landings for the three years prior to the BCRP to their post-rationalization landings, conditional on actively fishing in all years following the BCRP, the average ratio was 3.63.¹⁶ Given that vessels were awarded quota based on historical catch rates, this indicates that those vessels who participated in the post-rationalization era executed a cooperative consolidated IHQ that was over three and half times their own individual IHQ allocation. This is consistent with the contraction in capital utilization within the fishery during this time period (see Figure 2).

III. Empirical Model

To estimate the VSL we employ an empirical framework similar to that used by Ashenfelter and Greenstone (2004) and outlined in Ashenfelter (2006). On a given day t a vessel captain i decides between fishing and not. If she fishes, $Fish_{it} = 1$ (zero otherwise), the crew (and captain) face expected fishery-wide fatality risk f_t , to earn an expected individual economic return, R_{it} . If the captain decides

¹⁶ We estimated this ratio using only those vessels that fished in all years following the BCRP to account for the temporal adjustment in the capital restructuring and cooperative formation following rationalization.

to fish on a given day, she is implicitly deciding that the returns from fishing exceed the costs associated with the probability of a fatality. From this implicit tradeoff, we can recover an estimate of each captain's marginal rate of substitution between return and risk and then construct an estimate of the VSL. Following Ashenfelter and Greenstone (2004), we let V be the upper-bound estimate of the VSL from the sample of captains that decided to fish (no selection correction) and let V^* be the selection corrected estimate based on Heckman's (1979) selection model.

Estimating V

To recover our initial estimates of the vessel-specific tradeoffs being made within the red king crab fishery we estimate an earnings regression to recover a captain's marginal rate of substitution for risk. Using the fish ticket data we approximate the average daily gross revenues obtained per vessel per fishing trip.¹⁷ That is, R_{it} is total net revenues (to captain and crew) for each fishing trip divided by the number of days for that trip. Therefore we are assuming that over the course of a fishing trip the catch per day is the same. As such, the daily revenues for each vessel do not vary within a trip but do vary across trips. Ideally we would determine what revenues were obtained for each vessel on each day, but we do not observe daily production data for all vessels. Therefore, we construct daily revenue estimates by apportioning trip revenues across days fished, which may introduce some estimation bias. Fish ticket data only contain *gross* revenues, so we presently assume that the *net* revenues paid to captain and crew are 35% of the gross. In further research we will incorporate a more rigorous, vessel-specific specification of returns to captain and crew using detailed vessel cost data, but this approximation provides a ballpark estimate of their compensation.¹⁸ The regression model we estimate for each fishery is,

$$R(X_{it}; \beta) = \ln(R_{it}) = \beta_0 + \beta_1 \ln(\text{length}_i) + \beta_2 \ln(\text{hp}_i) + \beta_3 \ln(\text{hold}_i) + \beta_4 \text{USCG}_t + \beta_5 \text{BCRP}_t + \beta_6 \ln(\text{GHL}_t) + \beta_7 (\text{vessels}_t) + \beta_8 \ln(\text{fatal}_{it}) + \varepsilon_{it} \quad (1)$$

The vessel specific variables, length_i , hp_i and hold_i are vessel length, engine horsepower and hold capacity, respectively, which are the fixed production inputs. The policy dummy variables, USCG_t and BCRP_t capture the USCG Pre-Season Boarding Program and BCRP, respectively. The variable GHL_t is the gross harvest limit for each fishery in a given year, which is set at a pre-specified percentage

¹⁷ The revenues per day are in thousands of dollars and converted to 2007 dollars at an interest rate of 4%.

¹⁸ This information was obtained via consultation with researchers at the National Marine Fisheries Service who possess information on crew compensation in these fisheries. We are currently in the process of obtaining a more complete profile of vessel specific cost and revenue data that will refine our estimates.

of the spawning stock biomass each year and is used to control for stock abundance and yearly harvest constraints. The variable $vessels_t$ is the total number of vessels participating within the fishery in a given year and is used to capture potential congestion effects (Brown 1978; Hicks et al. 2008) and reduced earnings resulting from competition. The daily expected fatalities, $fatal_{it}$, is the fishery-wide expected daily fatality rate, f_t , multiplied by the number of individuals (FTE's) onboard vessel i on day t (the sum of the captain and the crew). This captures vessel-specific total expected fatalities that may result while at sea on a given day, and it is the coefficient on this variable, β_8 , that is the fleet-wide marginal rate of substitution between revenues and fatalities. We calculate f_t as $f_t = \max(AKf_t, Crabf_t)$, where $Crabf_t$ are the daily fatality rates for the crab fishery of interest (Table 2), and AKf_t are the annual fatality rates for all fisheries operating in the Bering Sea (an overall commercial fleet risk rate). AKf_t is calculated as a 1-year average of fatalities divided by FTEs at sea and based on the annual fatality risk data obtained from the NIOSH, Alaska Field Station. We construct the fatality rate in this way, because the number of vessels participating in the crab fisheries is small relative to the number of vessels fishing in all Alaskan waters, and we believe that the overall commercial fleet risk rates represent a minimum baseline level of risk that captains take into consideration in their fishing decisions.

One assumption of this model is that the captain cares for the welfare of his/her crew as well as herself in their risk-return tradeoff. That is, captains value their lives as equal to the value of a crew member's life. (If not, there would be separate MRS coefficients for captain and crew in equation 1.) In future research we plan to investigate this assumption further in an effort to recover the value of an altruistic life (the value that the captain places on a crew member's life only). Based on this specification, a consistent estimate of V (the sample-selection upper bound on the VSL) is the product of a consistent estimate of β_8 and some measure of expected revenues, divided by some measure of expected fatalities. For example, one could estimate a daily, vessel-specific $\hat{V}_{it} = \hat{\beta}_8 \times R_{it} / fatal_{it}$, where $\hat{\beta}_8$ is a consistent estimate of the MRS.¹⁹ One important limitation of this construction, and for most VSL studies, is that the measure of a captain's value of statistical life depends explicitly on the ratio of returns to fatalities.²⁰ Holding a vessel captain's marginal rate of substitution and the risk profile constant, a reduction in the

¹⁹ We do not contend that a captain's VSL is changing daily and ultimately report average VSL over time and vessels. However, we do not impose the time-invariant assumption *ex ante*.

²⁰ A similar discussion of this relationship was elaborated on in more detail in Jones-Lee (2004) in his theoretical model of the interaction between a developed and developing countries VSL in public policy when cross-country externalities are present.

daily returns will also reduce the implied VSL for the vessel (as the captain took on a given amount of risk for less compensation). However, the opposite holds true for days with high returns, and the goal of the model is to estimate the average VSL for the prevailing risks and returns observed in the fishery.

Within this decision environment, it is difficult to believe that the risks, f_t , are exogenous. That is, it is the decision of a captain to fish or not to fish that explicitly determines the risk that she (and the crew) faces. If she elects not to fish, this clearly affects the number of vessels and crew at risk and, hence, our risk measure. In some sense our measure of average daily risk over the past year (the daily moving average) will mitigate this problem, but instruments for risk are at our disposal and we use them in a two-stage least square exercise. In addition to the two dummy variables for policy changes we include wave height and an inclement weather variable, defined as the PPR index.²¹ Inclement weather is an important determinant of risk because it reduces vessel stability and increases the probability of tipping or capsizing. Wave height, not used in the calculation of the PPR, is also an important component of fatality risk, and we use the maximum daily wave height reported by the weather buoy within the BSAI.²²

The results from the second stage regression are in Table 4. The results indicate that larger vessels, as indicated by the length and hold capacity variables, earn higher daily revenues and that vessels with increased mobility, as indicated by horsepower, earn more as well. The results also show that daily revenues increased following the USCG Pre-Season Boarding Program (coefficient on BCRP is statistically insignificant). The initial revenue jump following the USCG cannot be attributed to the Pre-Season Boarding Program, because this time period also corresponded with a time of stock recovery following the near collapse of the red king crab fishery in the early 90's. The statistically significant and positive coefficient on GHL , illustrates that in years which the spawning biomass stock (and therefore the GHL) was larger, the mean revenues within the fishery increased, holding all else constant (i.e., the ex-vessel price effects). This is consistent with our expectations. The negative coefficient on the number of vessels participating within each fishery also confirms our expectations, however it is not statistically significant.

The coefficient of primary interest is that on instrumented daily fatalities, $fatal_{it}$, because it is an estimate of the marginal rate of substitution of revenue and risk within the fishery. Scaling this

²¹ The weather buoy data used in the analysis comes from station 46035. More information on this buoy can be obtained at the following link: www.ndbc.noaa.gov/station_page.php?station=46035. The buoy data used is the closest weather buoy to the fishing grounds within the BSAI that contained consistent data for the years 1997-2007. The PPR index is a transformation of weather data (wind speed, freezing point, air temperature, and sea water temperature) which is used to predict vessel icing. However, vessel icing is not an issue within the red king crab fishery (it is in other crab fisheries). We use the PPR to indicate inclement weather because it non-linearly transforms these different measures of weather to a single variable.

²² In some cases buoy data were unavailable, so we let these values be zeros and included a dummy variable in the regression equal to 1 if data were missing and zero otherwise.

coefficient by the ratio of the vessel-specific daily returns to the vessel-specific expected daily fatalities, we are able to recover a daily measure of each vessel's VSL, \hat{V}_{it} . These can be averaged over time and vessels to produce a fleet-wide VSL, $\bar{\bar{V}}$. This estimate represents an upper bound on the true VSL, because it excludes vessels that did not fish because their expected revenue was too low relative to fatality risk to fish, and, hence, their implied (and omitted) \hat{V}_{it} would have been relatively lower had it been observed.²³ This upper bound on the fleet-wide VSL is approximately \$5.49M (2007 dollars) in the red king crab fishery (Table 4). The value of these estimates are greater than those reported in the transportation risk literature (Ashenfelter and Greenstone, 2004) but lower than many of the reported measures within the general VSL literature (Viscusi, 1993).

Sample Selection Model

As discussed earlier, to consistently estimate the true underlying V^* we must account for sample selection present in the model (Ashenfelter 2006; Ashenfelter and Greenstone 2004). To estimate V^* we use the observed \hat{V}_{it} as the dependent variable in the main equation of a Heckman (1979) sample selection model. However, to recover the inverse mills ratio we must first estimate the probability that a captain decides to fish on a given day. The following probit model is estimated to recover this probability:

$$\begin{aligned} \Pr(Fish_{it} = 1) = & \omega_1 ExpRvn_{it} + \omega_2 USCG_t + \omega_3 BCRP_t + \omega_4 days_{it} \\ & + \omega_5 days_{it}^2 + \omega_6 Quota_{it} + \tau_{it} \end{aligned} \quad (3)$$

$ExpRvn_{it}$ are daily expected revenues from fishing. It is calculated using a lagged moving average of the daily estimated trip revenues derived within the fishery in the previous year. Another variable that influences the captains decision of whether or not to continue fishing is the length of the current trip, $days_{it}$, which is the number of days since the vessel left port. This variable is highly correlated with the remaining capacity of the vessel's live hold, and the length of time that crab have been in the hold exposing them to potential "dead-loss" which both influence a captain's decision to fish. The final variable used, $Quota_{it}$, represents the remaining available quota that a vessel has yet to land at each day during the season. It would logically follow that if they are out of quota they will stop fishing. This variable is constructed by summing up each vessel's landings in the post-BCRP period and then

²³ There are number of other factors that may contribute to a captain's decision to fish or not on a given day which we will control for in the sample selection correction of the VSL.

determining what percentage of their landings that year they had executed at a given point in time. This ex-post calculation acknowledges that the quota utilized by the vessel may reflect not only the vessel owner's quota contribution to the cooperative, but also other cooperative member's quota that was fished by this vessel. However, given that most of the quota execution decisions are made prior to the season beginning this variable captures the total amount of crab quota they fished in each year. The main equation estimated is,

$$\ln(\hat{V}_{it}) = \lambda_0 + \lambda_1(ExpRvn_{it}) + \lambda_2USCG_{it} + \lambda_3BCRP_{it} + \lambda_4 \ln(wave_{it}) + \lambda_5 \ln(PPR_{it}) + \rho\eta_{it} + v_{it} \quad (4)$$

where all variables are as defined earlier, and η_{it} is the inverse mills ratio (IMR). The empirical results from the Heckman model are in Table 5. The top panel is the probit equation and the bottom panel is the main equation.

The variables which appear to influence a captain's decision to fish (Table 5. upper panel) are the number of days since they have left port, the BCRP program, and the expected revenues within the fishery. The signs on the first-order and second-order terms for $days_{it}$ indicate that a vessel is more likely to stay out fishing if they have been fishing on the previous day, but beyond some point they decide to return to port to offload. This is consistent with a vessel filling their live hold and then returning to port. The coefficient on BCRP indicates that in the post-rationalization era a vessel decided to fish more days. The coefficient of expected revenues is not consistent with our *a priori* expectations regarding a vessel's decision to fish or not on a given day. However, upon closer inspection of the data we discovered that for a majority of the observations the expected revenues in the previous time period are greater than the current time period, indicating that there is a propensity for the daily revenues to decrease within a season. This statistical phenomenon appears to be driving the negative coefficient. Presumably fishermen are still electing to fish on a given day because the revenues they expect to derive exceed the variable costs they will incur despite the lower catch-per-a-unit of effort that exists within the fishery. Finally, the positive but statistically insignificant coefficient on a vessel's remaining quota is consistent with the belief that a vessel will decide to fish on a given day, if they have additional quota to fish. However, given the statistical insignificance of the variable, we can not confidently confirm this conjecture.

The estimates of equation 4, (Table 5, lower panel), indicate that our daily measure of the VSL is negatively influenced by expected daily revenues. Given that the VSL is estimated by multiplying a captain's marginal rate of substitution by the ratio of earnings to fatalities, these results imply that in the

red king crab fishery days with higher expected revenues also possess a higher fatality rate relative to days with lower expected returns. This causes the daily VSL estimate to be lower because the marginal rate of substitution is being held constant. Looking at the other variables in the model we see that both policy changes increased the VSL in the red king crab fishery. These results are consistent with the impact that these two policies have had on the daily risk profile. The weather variables used to proxy for the degree of risk on a given day illustrate that the PPR and the wave height had a positive and significant impact on the VSL. Finally, the statistically significant coefficient on the inverse mills ratio indicates that sample selection is an issue in our initial estimates of the VSL.

The sample selection corrected measure of the VSL, denoted \bar{V}^* in Table 5, are lower than our earlier estimates, which would be expected given the presence of our sample selection bias because our initial estimates of the VSL are an upper bound on the true underlying VSL. Therefore, our estimates of \bar{V}^* are "better" estimates of the VSL and indicate that VSL is approximately \$4.66M in the red king crab fishery, which is 15% lower than our estimates of \bar{V} . In addition to our estimates of \bar{V}^* , which are averages across the population of participating fishermen, we also observe individual measure of the VSL as well. Figure 5 illustrates the vessel specific measures of non-sample selected corrected measures of the VSL, denoted V_i , and the sample selection corrected measures of the VSL, denoted V_i^* , sorted from the lowest measure of V_i to the highest. The sample selection model reduces high V_i estimates (right side of the Figure) and increases those estimates which were too low (left side of the Figure). However, by and large, the V_i^* estimates predominately lie along our mean estimates of Table 5.

Heterogeneous VSL Estimation

Heterogeneity in fishing behavior has been well-documented in the literature. Commercial fishermen exhibit heterogeneous spatial behavior (Smith 2005), production methods (Flores-Lagunes et al. 2007; Felthoven et al. 2008), and risk perceptions (Mistean and Strand 2000). Given the prevalence of preference heterogeneity in commercial fisheries, especially with regard to risk preferences, it is plausible that different segments of the red king crab fishery possess different VSLs. This could be generated by either their misperceptions regarding the underlying risk (Viscusi 1990), or direct differences in their preferences, the latter manifesting itself in heterogeneous marginal rates of substitution for risk and returns. Therefore, it is important that we consider latent heterogeneity within our analysis. Furthermore, it has recently been theoretically demonstrated that failing to control for heterogeneity in an agent's ability to deal with work-related risk will bias the VSL estimates upward (Shogren and Stamland 2002). Using a

finite mixture model (Aitken and Rubin 1985; Swait 1994; MacLachlan and Peel 2000) to estimate V_{it} , we now control for this form of latent heterogeneity in our analysis.

The finite mixture model generalizes our reduced form expression of the revenue equation function, equation (1), by relaxing the assumption that β is a constant behavioral parameter across all fishermen. Instead we estimate $j = 1, \dots, J$ different segment-specific behavioral parameters, denoted $\beta_{1j}, \dots, \beta_{8j}$. We also estimate the probability that the behavior of fisherman i can be represented by the j^{th} set of coefficients, denoted P_{ij} , $j = 1, \dots, J$. Assuming a standard logit probability function, we have

$$P_{ij} = \frac{\exp(Z_i \gamma_j)}{\sum_{j=1}^J \exp(Z_i \gamma_j)}, \quad (5)$$

with fishermen-specific observation vector, Z_i , and segment-specific participation coefficients, γ_j . Given the high degree of heterogeneity in the vessel characteristics, we include two measures of vessel-specific capital structure (the vessels' net-tonnage and hold capacity) in Z_i . In addition, we include a variable indicating whether or not a vessel fished in the post-BCRP time period, $VesRat_i$. This last variable will serve to proxy for the latent ability of fishermen to cope with the risks present within the BSAI. Vessels which fished in the post-BCRP likely did so because they were the most efficient vessels and, in turn, could afford to pay other vessels for the right to land their quota. Although production efficiency would increase the probability that a vessel fished rather than leasing their quota to the cooperative and sitting idle, its ability to cope with the risks in the fishery would presumably also increase their probability of being selected. A vessel which is more stable in bad weather and better suited to cope with the prevailing weather conditions will be more desirable to fish than one which is instable. Given the probability statement in equation (5) the full likelihood function for the equation (1) with heterogeneous vessels is,

$$L = \prod_{i=1}^N \prod_{t=1}^{T_i} \sum_{j=1}^J P_{ij} R(X_{it}; \beta_j) \quad (6)$$

where T_i denotes total daily observations for fishermen i , N is the total number of fishermen in the dataset, and $R(X_{it}; \beta_j)$ is the revenue function in equation (1) with parameters $\beta_j = \beta_{1j}, \dots, \beta_{8j}$

substituted for β_1, \dots, β_8 . To determine the appropriate number of segments to use in the finite mixture model the Bayesian Information Criterion and corrected Akaike Information Criterion were used (MacLachlan and Peel 2000). These tests were conducted by first estimating the $J = 1$ (homogenous β) model and then increasing the number of segments until the test statistics unilaterally indicated that the previous number of segments was the best. The test results are in Table 6 and indicate that the best model specification is $J = 2$.

Given the multi-stage nature of our empirical model we estimate the finite mixture regression for only equation (1) (after instrumenting fatality rates). Equation (1) is the most important stage of the model because it determines the upper bound on our estimates of the VSL and is the obvious place to control for vessel heterogeneity. The sample selection portion of the model is used to uncover the true underlying VSL and is therefore preserved except for one aspect of the model. In equation (4) the constant is broken down into the respective segments by using the probability of segment participation predicted by our parameter estimates in equation (5) as independent variables in the model.

The empirical results for the finite mixture model are in Tables 7. The segment participation probabilities have been normalized on segment one, therefore we do not report parameter estimates for $j = 1$. The probability that a vessel exhibits behavior consistent with segment 2 is increasing with a vessel's net-tonnage and decreasing in their hold capacity. Furthermore, those vessels which fished in the post-BCRP period were less likely to be in segment 2. One important feature of the finite mixture model is that it does not precisely partition the vessels into either segment one or two. Instead, each vessel i possesses an estimated probability of being in both segments, \hat{P}_{i1} and \hat{P}_{i2} respectively. The vessel specific behavioral parameters can be recovered by multiplying their vessel specific segment probabilities by the estimated behavioral parameter and summing over the segments. This allows us to recover vessel specific measures of the marginal rate of substitution for risk and returns. Each vessels marginal rate of substitution was calculated as follows,

$$MRS_i = \sum_{j=1}^J \hat{P}_{ij} \hat{\beta}_{8j}, \quad (7)$$

which is used to estimate the vessel-specific, finite mixture (FM) measures of \hat{V}_i^{FM} , the dependent variable in the sample selection model of equation 4. Figure 5 illustrates the finite mixture model estimates of MRS_i . From this figure it is evident that the homogeneous model, ($J = 1$), under-estimates the marginal rate of substitution within the fishery.

The β_j estimates for the $j = 2$ segment are very similar to those in Table 4. The variable of primary interest is the vessel specific measure of the marginal rate of substitution. Given the differences in our estimates of MRS_i , we would expect our estimates of the VSL in the red king crab fishery to increase relative to the homogeneous model, ($J = 1$). This is precisely what we observe. The finite mixture (FM) estimates of \bar{V} , denoted \bar{V}^{FM} in Tables 7, are greater than those in Table 4, indicating that our initial estimates of the VSL were biased downward. Furthermore, this persists when we correct for sample selection, resulting in a VSL estimate, denoted \bar{V}^{FM*} in Table 8, that is just over 5% higher than in the homogeneous model, \bar{V}^* .

These finite mixture results suggest that there is a bias when assuming a homogeneous preference model, $J = 1$, relative to a model in which we account for latent heterogeneity. However, the biases observed are not consistent with Shogren and Stamland's (2002) theoretical result that ignoring heterogeneity will bias our estimates of the VSL upward. In our model ignoring heterogeneity biases them downward. However, our notion of heterogeneity does not perfectly correlate with Shogren and Stamland's argument, which may explain the difference. Although further elaboration is beyond the scope of this research, future research on this form of heterogeneity may benefit from using Shogren and Stamland's GMM estimation algorithm to control for heterogeneity (Shogren and Stamland 2006).

IV. Conclusions

This research estimates the VSL for one of the riskiest occupations, which has recently been popularized as "The Deadliest Catch" by the Discovery Channel's reality TV show. Using two recent policy changes within the BSAI crab fisheries as well as weather data, we instrument for the endogenous daily risk present and investigate the structural breaks in the risk profile resulting from these policies. Our estimates of the VSL range from \$4.6M to \$4.9M depending on the modeling assumptions. These estimates control for the inherent sample selection bias present in many VSL estimates and, when compared to those estimates which do not control for sample selection, illustrate the substantially upward biases which may arise (Ashenfelter 2006). In addition, these estimates are robust to heterogeneous preferences which bias our homogeneous estimates of the VSL.

In future research we will estimate the VSL using similar data from the Alaskan Snow/Tanner crab fishery. This fishery operates at a different time of year (winter) where weather-related risks are higher and where the market value of the catch is lower. Since vessels and crew frequently operate in both the King and Snow crab fisheries, it would be interesting to see if our \$4.6-4.9M estimate of the VSL is stable across the two, given that the fisheries have entirely different risk-reward profiles. Also,

our estimate of the VSL is based on the risk-reward trade-offs made by the captain for herself and the entire crew. It is, therefore, a vessel-wide, average VSL. In future research it may be possible to disaggregate the risk-reward profile into a captain component and a crew component. This will allow us to test hypothesis on differences between the VSL that a captain ascribes to herself and to her crew. The extent to which captains value the lives of their crew may be interpreted as a measure of altruism or "other regarding preferences" (Andreoni and Miller 2002, Fehr and Schmidt 1999; Cox et al. 2007; Cox et al. 2008).

References

- Aitken, M. and D.B. Rubin. 1985. Estimation and hypothesis testing in finite mixture models. *Journal of the Royal Statistical Society, B* 47: 67-75.
- Anderson, L. 1991. A note on market power in ITQ fisheries. *Journal of Environmental Economics and Management* 21:291-6.
- Andreoni, J., Miller, J. 2002. Giving according to GARP: An experimental test of the consistency of preferences for altruism. *Econometrica* 70: 737-53.
- Ashenfelter, O. and M. Greenstone. 2004. Using mandated speed limits to measure the VSL. *Journal of Political Economy* S226-67.
- Ashenfelter, O. 2006. Measuring the VSL: problems and prospects. *The Economic Journal* 116: C10-C23.
- Atkinson, S.E. and R. Halverson. 1990. The valuation of risks to life: evidence from the market for automobiles. *Review of Economics and Statistics* 72: 133-36.
- Black, D.A. and T.J. Kniesner. 2003. On the measurement of job risk in hedonic wage models. *Journal of Risk and Uncertainty* 27(3):205-20.
- Blomquist, G. 1979. Value of life saving: implications of consumption activity. *Journal of Political Economy* 87: 540-58.
- Brown, G. 1978. An optimal program for managing common property resources with congestion externalities. *Journal of Political Economy* 82: 163-74.
- Bureau of Labor Statistics (BLS). 2006. National census of fatal occupational injuries in 2006. available online at: <http://www.bls.gov/iif/oshcfoi1.htm>
- Cheung, S.N.S. 1970. The structure of a contract and the theory of a non-exclusive resource. *Journal of Law and Economics* 13: 49-70.
- Clark, C.W. and G. Munro. 1980. Fisheries and the processing sector: some implications for management policy. *Bell Journal of Economics* 11:603-16.
- Cox, J.C., Friedman, D. and S. Gjerstad. 2007. A tractable model of reciprocity and fairness. *Games and Economic Behavior* 59: 17-45.
- Cox, J.C., Friedman, D. and V. Sadiraj. 2008. Revealed altruism. *Econometrica* 76: 31-69.
- Dreyfus, M.K. and W.K. Viscusi. 1995. Rates of time preference and consumer valuation of automobile safety and fuel efficiency. *Journal of Law and Economics* 38: 79-105.
- Evans, W.N. and W.K. Viscusi. 1991. Estimation of state-dependent utility functions using survey data. *Review of Economics and Statistics* 73:94-104.
- Fehr, E., Schmidt, K. 1999. A theory of fairness, competition and cooperation. *Quarterly Journal of Economics* 114: 817-68.

- Felthoven, R.G., Horrace, W.C. and K.E.Schnier. 2008. Estimating Heterogeneous Capacity and Capacity Utilization in a Multi-Species Fishery. *Working paper, Department of Environmental and Natural Resource Economics, University of Rhode Island.*
- Flores-Lagunes, A., Horrace, W.C. and K.E. Schnier. 2007. Identifying technically efficient fishing vessels: A non-empty, minimal subset approach. *Journal of Applied Econometrics* 22: 749-45.
- Fuchs, V.R. and R. Zeckhauser. 1987. Valuing health – a 'priceless' commodity. *American Economic Review* 77(2): 263-8.
- Gayer, T., Hamilton, J.T. and W.K. Viscusi. 2000. Private values of risk tradeoffs at superfund sites: housing market evidence on learning about risk. *Review of Economics and Statistics* 82: 439-51.
- Ghosh, D., Lee, D. and W. Seal. 1975. Optimal motorway speed and some valuations of time and life. *Manchester School of Economics Social Studies* 43: 134-43.
- Gordon, H.S. 1954. The economic theory of a common property resource: the fishery. *Journal of Political Economy* 62:124-42.
- Hannesson, R. 2004. *The Privatization of the Oceans*. MIT Press: Cambridge, MA.
- Hardin, G. 1968. The tragedy of the commons. *Science* 162:1243-48.
- Heckman, J.J. 1979. Sample selection bias as a specification error. *Econometrica* 47:153-62.
- Hicks, R.L., Horrace, W.C. and K. E. Schnier. 2008. Congestion externalities and fishing vessels: the game of where to fish? *Unpublished Manuscript, Department of Economics, Syracuse University.*
- Homans, F. and J.E. Wilen. 1997. A model of regulated open-access resource use. *Journal of Environmental Economics and Management* 32:1-21.
- Hultkrantz, L., Lindberg, G. and C. Andersson. 2006. The value of improved road safety. *Journal of Risk and Uncertainty* 32: 151-70.
- Jones-Lee, M. 2004. Valuing international safety externalities: does he "golden-rule" apply? *Journal of Risk and Uncertainty* 29: 277-87.
- Jones-Lee, M. 1991. altruism and the value of other people's safety. *Journal of Risk and Uncertainty* 4: 213-9.
- Jones-Lee, M.W. 1974. The values of changes in the probability of death or injury. *Journal of Political Economy* 82: 835-49.
- Kniesner, T.J., Viscusi, W.K., Woock, C. and J.P. Ziliak. 2006. Pinning down the value of statistical life. *Center for Policy Research Working Paper No. 85, Maxwell School of Citizenship and Public Affairs, Syracuse University.*
- Krupnick, A. 2007. Mortality-risk valuation and age: stated preference evidence. *Review of Environmental Economics and Policy* 1(2): 261-82.
- Krupnick, A. and M.L. Cropper. 1992. The effect of information on health risk valuations. *Journal of Risk and Uncertainty* 5: 29-48.

- Libecap, G.D. 2006. The assignment of property rights on the western frontier: lessons for contemporary environmental and resource policy. National Bureau of Economic Research, Inc., *NBER Working Paper No. 12598*.
- Lincoln, J.M. and G.A. Conway. 1999. Preventing commercial fishing deaths in Alaska. *Occupational and Environmental Medicine* 56: 691-5.
- Lucas, D.L. and J.M. Lincoln. 2007. Fatal falls overboard on commercial fishing vessels in Alaska. *American Journal of Industrial Medicine* 1-7.
- Matulich, S., Mittlehammer, R. and C. Reberte. 1996. Toward a more complete model of individual transferable fishing quotas: implications of incorporating the processing sector. *Journal of Environmental Economics and Management* 31: 112-28.
- Matulich, S. and M. Sever. 1999. Reconsidering the initial allocations of ITQs: The search for a Pareto-safe allocation between fishing and processing sectors. *Land Economics* 75: 203-19.
- McConnell, K.E. and M. Price. 2006. The lay system in commercial fisheries: the origin and implications. *Journal of Environmental Economics and Management* 51: 295-307.
- MacLachlan, G. and D. Peel. 2000. *Finite Mixture Models*. John Wiley & Sons, Inc. New York.
- Mistiaen, J.A. and I.E. Strand. 2000. Location choice of commercially fishermen with heterogeneous risk preferences. *American Journal of Agricultural Economics* 82: 1184-1190.
- National Oceanic and Atmospheric Administration (NOAA). 2007. Bering Sea and Aleutian Islands crab rationalization report fishing year 2006/2007. *NOAA Fisheries (NMFS), Alaska Region Restricted Access Management (RAM), November 2007*.
- Neher, P.A., Arnason, R. and N. Mollett. 1989. *NATO Advanced Research Workshop on Scientific Foundations for Rights Based Fishing*. Dordrecht, Boston: Kluwer Academic Publishers.
- North Pacific Fishery Management Council (NPFMC). 2006. Stock assessment and fishery evaluation report for the king and tanner crab fisheries of the Bering Sea and Aleutian Islands regions. *Compiled by The plan team for the king and tanner crab fisheries of the Bering Sea and Aleutian Islands*.
- Portney, P.R. 1981. Housing prices, health effects, and valuing reductions in risk of death. *Journal of Environmental Economics and Management* 8:72-8.
- Rosen, S. 1986. the theory of equalizing differences. In *Handbook of Labor Economics*, eds. O. Ashenfelter and R. Layard. Amsterdam: New Holland, pgs. 641-92.
- Shogren, J.F. and T. Stamland. 2006. Consistent estimation of the value of statistical life. *Resource and Energy Economics* 28: 262-81.
- Shogren, J.F. and T. Stamland. 2002. Skill and the value of life. *Journal of Political Economy* 110: 1168-1173.

- Sorum, A.J. 2003. Evaluation of Alaska's commercial fishing vessel safety program. In National Institute for Occupational Safety and Health (NIOSH). *Proceedings, Second International Fishing Industry-Safety and Health Conference, September 22-24, 2003. Sitka, AK.*
- Smith, M.D. 2005. State dependence and heterogeneity in fishing location choice. *Journal of Environmental Economics and Management* 50: 319-340.
- Smith, V.L. 1968. Economics of production from natural resources. *American Economic Review* 56: 409-431.
- Smith, V.L. 1969. On models of commercial fishing. *Journal of Political Economy* 77: 181-198.
- Swait, J. 1994. A Structural Equation Model of Latent Segmentation and Product Choice for Cross-Sectional Revealed Choice Data. *J. Retail. Cons. Serv.* 1: 77-89.
- Thaler, R. and S. Rosen. 1976. The value of saving a life: evidence from the market. In *Household Production and Consumption*, ed. N.E. Terleckyz. New York: Columbia University Press.
- Viscusi, W.K. 1990. Sources of Inconsistency in Societal Responses to Health Risks. *American Economic Review, Papers and Proceedings* 80: 257-61.
- Viscusi, W.K. 1993. The value of risk to life and health. *Journal of Economic Literature* 31: 1912-46.
- Viscusi, W.K., Magat, W.A. and J. Huber. 1987. An investigation of the rationality of consumer valuations of multiple health risks. *RAND Journal of Economics* 18:465-79.
- Viscusi, W.K. and J.E. Aldy. 2003. The value of a statistical life: a critical review of market estimates throughout the world. *Journal of Risk and Uncertainty* 27(1):5-76.

Figures and Tables

Table 1. Descriptive Statistics for the Red King Crab Fishery.

Pre-Rationalization Descriptive Statistics

Red King Crab Fishery				
<u>Variable</u>	<u>Mean</u>	<u>Standard Dev.</u>	<u>Maximum</u>	<u>Minimum</u>
Trip Revenues	107,632.27	108,095.08	837,497.05	0.00
Lbs. Harvested	26,386.58	22,929.85	169,261.00	0.00
Trip (days)	7.53	2.36	19.00	1.00
Vessel Length	114.17	27.00	204.00	43.00
Hold Cap. (lbs.)	10,133.61	18,167.96	220,000.00	384.00
Net-tonnage	148.71	103.07	879.00	10.00
Horsepower	1032.05	582.67	6000.00	238.00

Post Rationalization Descriptive Statistics

Red King Crab Fishery				
<u>Variable</u>	<u>Mean</u>	<u>Standard Dev.</u>	<u>Maximum</u>	<u>Minimum</u>
Trip Revenues	78,136.06	124,197.46	888,450.31	0.00
Lbs. Harvested	19,719.45	30,259.61	216,320.00	0.00
Trip (days)	9.10	3.31	23.00	1.00
Vessel Length	116.27	21.98	180.00	77.00
Hold Cap. (lbs.)	12,241.41	25,135.00	220,000.00	1,000.00
Net-tonnage	153.01	107.96	879.00	49.00
Horsepower	1,049.43	472.80	4000.00	375.00
Annual Landings	193,138.42	296,818.93	1,738,461.30	21,335.00

Table 3: Instrumented Daily Risk Rate Regression Results: standard errors in parentheses.

Red King Crab	
Parameter	Fishery
θ_0 (<i>const</i>)	-5.4752** (0.17)
θ_1 (<i>PPR</i>)	0.1386** (0.06)
θ_2 (<i>PPR</i> ²)	-0.0473** (0.02)
θ_3 (<i>wave</i>)	0.3053** (0.13)
θ_4 (<i>wave</i> ²)	-0.0954** (0.02)
θ_5 (<i>USCG</i>)	-0.3154** (0.16)
θ_6 (<i>BCRP</i>)	-1.1233** (0.12)
<i>N</i>	276
<i>LL</i>	-290.73

(** indicates statistical significance at the 95% level)

Table 4: Regression estimates of $\ln(R_{it})$.

Red King Crab	
Parameters	Fishery
β_0 (<i>const</i>)	-3.4287** (0.17)
β_1 (<i>length</i>)	0.8978** (0.04)
β_2 (<i>hold</i>)	0.1821** (0.02)
β_3 (<i>hp</i>)	0.0366** (0.01)
β_4 (<i>USCG</i>)	0.5340** (0.01)
β_5 (<i>BCRP</i>)	-0.1359 (0.14)
β_6 (<i>GHL</i>)	0.2270** (0.02)
β_7 (<i>Vessels</i>)	-0.1131 (0.12)
β_8 (<i>fatal^{IV}</i>)	0.0705** (0.01)
\bar{V}	\$5.49M
N	17,788
LL	-16,858.06

(** indicates statistical significance at the 95% level)

Table 5: Sample Selection Estimation of V^*

Selection Equation	
Parameter	Red King Crab
ω_1 (<i>ExpRvn</i>)	-0.1201** (0.01)
ω_2 (<i>USCG</i>)	0.7396 (0.51)
ω_3 (<i>BCRP</i>)	5.9069** (2.98)
ω_4 (<i>days</i>)	0.8400** (0.03)
ω_5 (<i>days</i> ²)	-1.3119** (0.05)
ω_6 (<i>Quota</i>)	1.1760 (0.05)
N	37,572
LL	7,054.67
Main Equation	
λ_0 (<i>const</i>)	17.8018** (0.08)
λ_1 (<i>ExpRvn</i>)	-2.0473** (0.04)
λ_2 (<i>USCG</i>)	1.4174** (0.02)
λ_3 (<i>BCRP</i>)	1.3477** (0.02)
λ_4 (<i>wave</i>)	0.2101** (0.01)
λ_5 (<i>PPR</i>)	1.2085** (0.08)
$\rho\sigma$ (<i>IMR</i>)	-0.0511** (0.01)
\bar{V}^*	\$4.66M
N	17,788
LL	19,723.87

(** indicates statistical significance at the 95% level)

Table 6: Finite Mixture Model Specification Tests

Model	Red King Crab	
	BIC	crAIC
$J = 1$	33,804.20	33,734.12
$J = 2$	30,752.60	30,589.14
$J = 3$	30,840.20	30,613.21

Table 7: Finite Mixture Results for the Red King Crab fishery

Segment Participation Variables		
Parameter	Segment 1	Segment 2
<i>VesRat</i>	-----	-1.6457** (0.28)
<i>Hold</i>	-----	0.9168** (0.09)
<i>Net – tons</i>	-----	-0.0111** (0.01)
Segment Estimates of V		
β_{0j} (<i>const</i>)	-10.3871** (2.15)	-3.4510** (0.15)
β_{1j} (<i>length</i>)	2.1660** (0.47)	0.8904** (0.03)
β_{2j} (<i>hold</i>)	0.4810* (0.26)	0.1565** (0.01)
β_{3j} (<i>hp</i>)	-0.4118** (0.15)	0.0411** (0.01)
β_{4j} (<i>GHL</i>)	1.1773** (0.35)	0.1895** (0.02)
β_{5j} (<i>vessels</i>)	-4.8929** (1.55)	0.2921** (0.10)
β_{6j} (<i>USCG</i>)	0.8547** (0.27)	0.5506** (0.01)
β_{7j} (<i>BCRP</i>)	-8.3473** (1.77)	0.4364** (0.12)
β_{8j} (<i>fatal^{IV}</i>)	-0.0081 (0.11)	0.0778** (0.01)
\bar{V}^{FM}		\$5.916M (\$5.929M)
N		17,788
LL		-15,273.54

(** indicates statistical significance at the 95% level; * indicates statistical significance at the 90% level. VSL estimates contained in parenthesis assume that the coefficient on fatalities in segment two is zero because the coefficient is not statistically significant from zero.

Table 8: Main Equation Estimation for the Finite Mixture Model

Parameter	Red King Crab
$\text{Pr}(Seg = 1)$	22.0488** (0.43)
$\text{Pr}(Seg = 2)$	17.8109** (0.08)
λ_1 (<i>ExpRvn</i>)	-2.0508** (0.04)
λ_2 (<i>USCG</i>)	1.4140** (0.02)
λ_3 (<i>BCRP</i>)	1.2668** (0.02)
λ_4 (<i>wave</i>)	0.2110** (0.01)
λ_5 (<i>PPR</i>)	1.2078** (0.08)
$\rho\sigma$ (<i>IMR</i>)	-0.0515** (0.01)
\bar{V}^{FM*}	\$4.905M (\$4.916M)
<i>N</i>	17,788
<i>LL</i>	-19,645.60

(** indicates statistical significance at the 95% level; *indicates statistical significance at the 90% level.

VSL estimates contained in parenthesis assume that the coefficient on fatalities in segment two for the red king crab fishery is zero, used to generate the dependent variable in the main equation, because the coefficient is not statistically significant from zero.)

Figure 1: Annual Fatality Rates per a 100,000 workers (converted FTEs) in all of Alaska and the Alaskan Crab Fisheries. (source data obtained from Jennifer Lincoln, NIOSH – Alaska Field Station) – State crab fishery fatalities removed for 2006 because they were not rationalized.

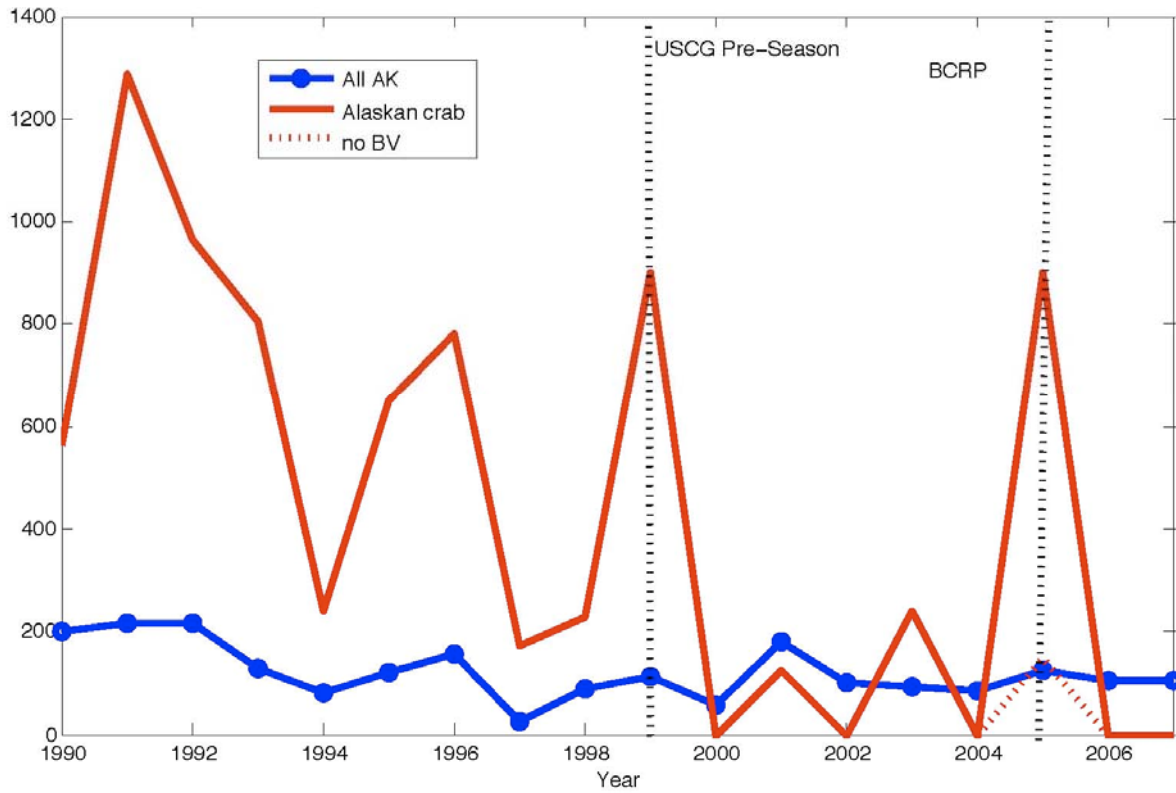


Figure 2: Number of fishing vessels (blue) and season length (green) by year.
(vessels = upper curve before 2004; days fished=lower curve before 2004).

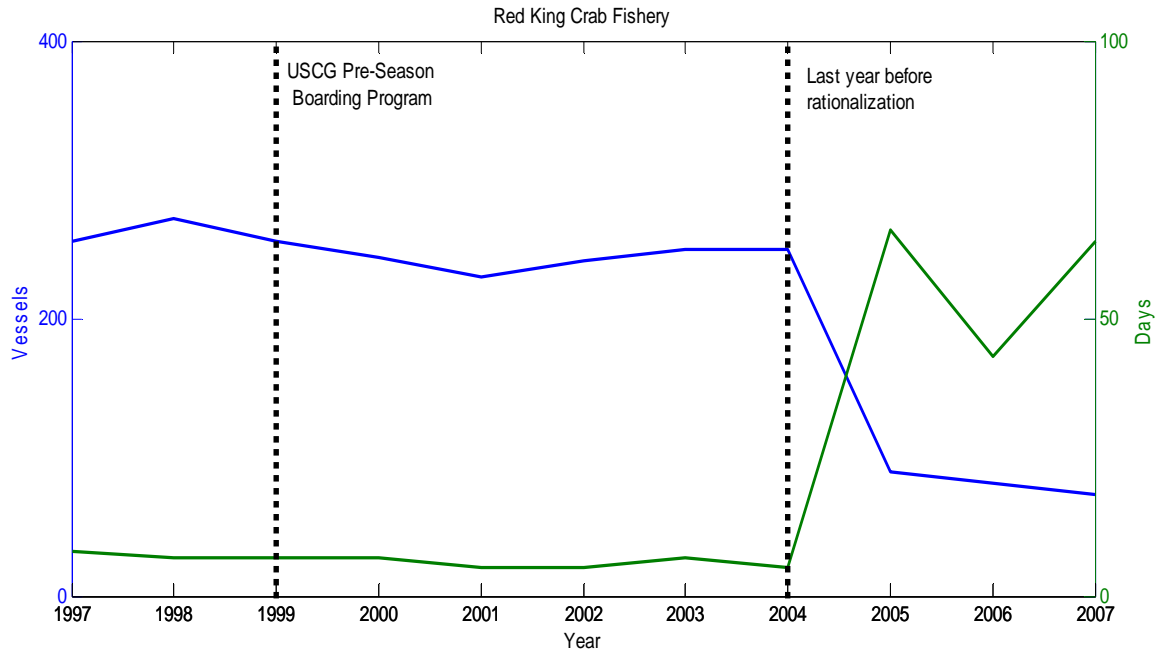


Figure 3: Full-time equivalence employment rates by year.

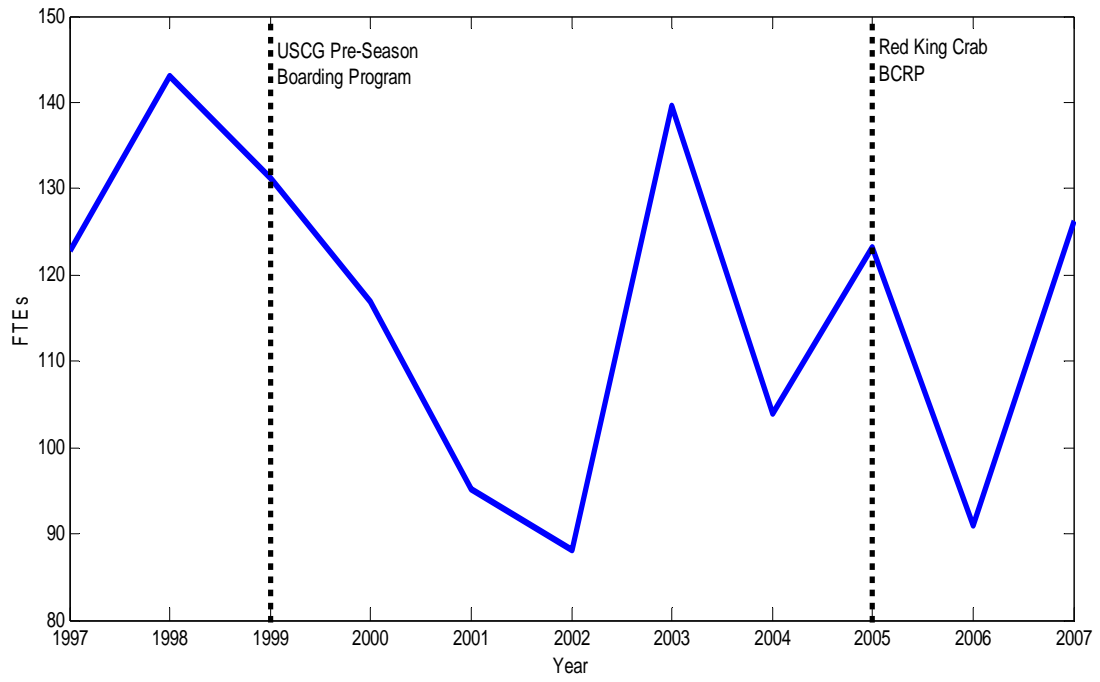


Figure 4: Mean vessel specific VSL estimates prior to sample selection correction V_i and following sample selection correction V_i^* in the red king crab fishery.

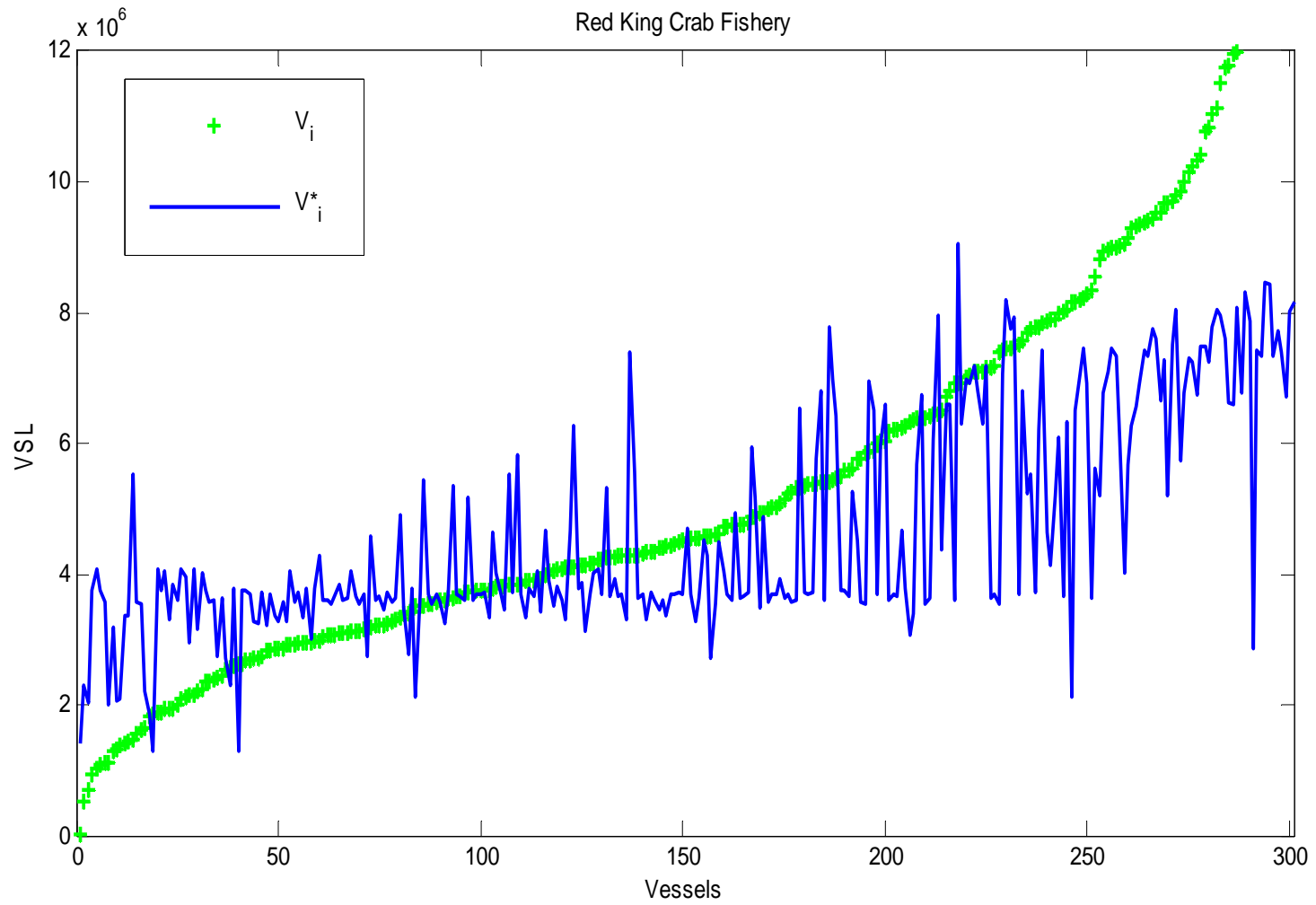


Figure 5: Finite Mixture estimates of the marginal rate of substitution for earnings and risk, MRS_i .

