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A Market Model of the Alaskan King Crab Industry

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and Ron C. Mittelhammer

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A MARKET MODEL OF THE ALASKAN KING CRAB INDUSTRY

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ABSTRACT

The market model for red king crab (Paralithodes camtschatica) traces the harvest of crab through various levels of processing and storage, ultimately to wholesale market distributions. Two segmentable equilibrium relationships are modeled: one determining the ex-vessel price of raw king crab, the other determining the wholesale price of processed crab products. The market for raw king crab is characterized as a bilateral monopoly in which processors have a derived demand for raw crab and consider harvest costs facing fishermen when making ex-vessel price offers. The supply of raw crab to processors is estimated with three behavioral relations (quantity harvested, fishing effort, and stock of vessels). Eight definitional identities complete the raw crab market model. The wholesale market for processed crab products is modeled as an equilibrium between consumer demand and processor/cold storage operator derived supply. This interface is modeled with four behavioral equations (wholesale section, wholesale meat price, section consumption, and section holdings) and three definitional identities. A complete behavioral model is estimated only for the southeastern Bering Sea fishery management area during 1968 through 1983. Harvest in the rest of the state is treated as a market clearing residual.

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INTRODUCTION

The Alaskan king crab industry[3/] is in a transition period, recovering from a dramatic boom-bust cycle. Statewide harvests began an unprecedented period of growth in 1969 that continued through 1980. Harvests more than tripled, culminating in record catches of 185.7 million pounds in 1980. Increased fishing effort in the Bristol Bay fishery management area was largely responsible for the boom; Bristol Bay harvests rose from 8.6 million pounds in 1970 to the record catch of 130 million pounds in 1980. Within 3 years, however, the industry collapsed. King crab stocks were so scarce that the Alaska Department of Fish and Game (ADF&G) ordered complete closure of the Bristol Bay fishery. Statewide harvests plummeted to 26.9 million pounds. An additional 10 million pounds were lost by 1985 (U.S. Department of Interior 1947-75; Alaska Department of Fish and Game 1969-83, 1970-85).

The economic wake of this collapse has been extensive, involving virtually every participant in the fishery. Between 1980 and 1983, ex-vessel revenues to fishermen fell by more than 50%, dropping by $93.2 million. Processor sales dropped $178.0 million (a 60% reduction), while sales from wholesalers declined by $304.2 million (a 66% reduction).

[3/] "King crab" is the common name given to three crustaceans in the family of stone crabs, Lithodidae. The three species are the red king crab (Paralithodes camtschatica), the blue king crab (Paralithodes platypus), and the brown or golden king crab (Lithodes aequispina). All three species inhabit waters of the north Pacific Ocean. They are similar in appearance though noticeably varied in shell color. The red king crab has been the cornerstone of the Alaskan king crab industry because of its large size; shallow, inshore distribution; and historically greater abundance. The other two king crab species, though harvested commercially, have been much less abundant and restricted to more localized and remote habitats. Harvest pressure and commercial importance of these two species has increased during the past 6 years principally because red king crab stocks have declined; only limited (primarily incidental) catches were made prior to 1981.

Multimillion dollar fishing vessels were idled, others shifted into different. fisheries, processing plants closed and an industry-wide restructuring commenced.

The significance of the collapse may be placed in perspective by considering the fact that the king crab fishery was the second most valuable Alaska seafood industry between 1968 and 1983. Only the combined value of all six salmonid species harvested in Alaska exceeded that of king crab (Alaska Department of Fish and Game, 1969-83). Yet, the statewide king crab catch rarely exceeded one-third the total catch of salmon, by weight.

The impact of the collapse extends well beyond the Alaskan economy. Butcher et al. (1981) identified direct linkages between the shellfish sector and the economy of the Puget Sound area in western Washington. Only 32% of total shellfish revenues were returned to the Alaskan economy in direct purchases of goods and services. Much of the remaining 68% was spent in the Seattle area for vessel maintenance and construction, gear and supplies, and general consumer goods. Moreover, most of the processing and cold storage firms were based in the Seattle area. The diminished flow of processed king crab products to domestic and foreign markets also caused a tripling of nominal wholesale and retail prices between 1980 and 1986 (National Marine Fishery Service 1969-84).

Short of blaming the open access milieu of this common property fishery, specific causes or contributing factors to the collapse must be identified if policymakers are to contribute to a recovery. Resolution of the underlying bioeconomics is essential in this regard. This report is one in a series of three that collectively comprise a bioeconomic analysis of the Alaskan king crab industry; it addresses the Alaskan king crab market, from initial harvest to final consumption. A second report (Matulich, Hanson and Nittelhammer 1988b) examines the population dynamics of this fishery and establishes the age-structured biological response submodels. The biological and economic submodels are integrated in the report (Matulich, Hanson and Mittelhammer 1988a) to simulate industry responses under a variety of historical and potential future policy scenarios.. The research findings contained in these three reports are intended to provide insight into future management of the fishery.

The market submodels presented in this report incorporate the behavior of fisheries managers and policymakers, fishermen, processors, cold storage operators, and consumers into the overall king crab bioeconomic framework. Fisheries managers and policymakers regulate total harvest. Fishermen, given a legally harvestable resource base, produce the primary supply of raw crab. Processors purchase raw crab from fishermen based on their derived demands for king crab. The purchased crab is processed into a supply of king crab products for wholesale and retail markets. A portion of this derived supply may be held in storage for later release to the wholesale market., Finally, processors and cold storage operators confront the-primary demands of wholesale customers with these derived supplies of king crab products. All model variables used throughout this report are defined and sources referenced in Appendix 1. Subscripts on variables refer to time.

Simultaneity in this market system is divided into two segmentable components, each based on price. There is simultaneity between primary supply and derived demand, whereby fishermen and processors negotiate to reach an equilibrium ex-vessel (harvest) price. Ex-vessel price is modeled as a processor price offer function that is based on derived demand. Simultaneity also exists between wholesalers and processors/cold storage operators at the interface between primary demand and derived supply. The wholesale price equilibrates these two components. Linkage of the primary demand/derived supply components with those of derived demand/primary supply conceptually occurs via a lagged average of wholesale product prices (i.e., a predetermined variable).

Simultaneity characteristics of the system and the limited number of historical observations (only 15 years of data, 1969-83) dictated choice of regression techniques. All structural relationships having explanatory endogenous variables were estimated using either linear or nonlinear two-stage least squares (2SLS), depending on functional form. Principal components were used as instruments to reduce the number of explanatory variables in the reduced form estimation. In contrast, the fleet size equation ($VESSELS_t$) could be segmented from the system because it was dependent only on predetermined variables. Nonlinear ordinary least squares was used to estimate this relationship. Regressions were weighted to correct for heteroskedasticity in several cases. The variance of the dependent variable was specified to be proportional to the square of the endogenous variable; weights were equal to the inverse of that variable.

Four criteria collectively were used to judge the goodness of statistical fit and to refine the empirical regression specifications: 1) sign and magnitude consistency of the parameter estimate with a priori reasoning and previous studies; 2) statistical significance of the estimates, as measured by the t-test reported parenthetically below the corresponding coefficient; 3) explanatory power of the estimated equations as measured by the coefficient of determination (R^2); and 4) the relationship's ability to predict historical observations and turning points of the dependent variable, as indicated by graphical comparison of observed versus predicted age class recruitment. All four of these criteria need to be considered because of the limited data set.

Data limitations required that the Alaskan king crab fishery be divided geographically into two regions based on ADF&G vessel registration area designations: 1) the southeastern Bering Sea (designated area T), and 2) an aggregate of all other king crab harvest areas (collectively referred to as area W). A complete harvest model could be derived only for area T; inadequate biological data for the aggregate region precluded development of a similar structural framework. Harvest in area W ($QHARVW_t$) is modeled as a market clearing residual between $QHARVT_t$ and total processed production.

PRIMARY SUPPLY: THE HARVEST SECTOR

Quantity Harvested in Bristol Bay ($QHARVT_t$)

Two features of this fishery appear to legitimize a simplified view of the harvest sector, a view in which quantity harvested is exogenous: 1) a harvest guideline level (GHL) is announced prior to the fishing season, and 2) the -fishery is closed by emergency order. The GHL is not a quota that functionally limits the fishing season. Rather, it is a wide range of potential harvest levels that fishery managers believe could be supported by beginning stock conditions. Actual harvest exceeded the upper GHL 4 of 12 years between 1972 and 1983, and fell below the lower GHL in one year. Since fishing continues until closure, one might presume that the marginal revenues from fishing exceed marginal costs; the quantity harvested would appear to be determined exogenously by the closure decision.

The closure decision, however, is a function of key indicators of intraseasonal fishery health--primarily, catch per unit effort (CPUE) and the soft-shell condition of crab. Catch per unit effort in turn is a function of the actual unharvested crab stock and the amount of fishing effort applied, which is a function of economic incentives. Since CPUE is endogenous to the system, and since the closure decision is a function of CPUE, the closure decision itself is endogenous, as is the resulting quantity harvested. The appearance that quantity harvested is exogenous in this fishery is illusory.

Freebairn and Rausser (1975) developed a framework to model the policy process per se in the context of U.S. beef import policy. Due to the complexity of their analysis, it has not been widely applied to other commodities. Extending a similar framework to the Alaskan king crab fishery is also considered too complex in the context of this first attempt at a bioeconomic model of the entire fishery.. Accordingly, actual season length ($DAYS_t$), although endogenously determined by policymakers, is treated as exogenous, while quantity harvested, the behavior of fishermen and processors, and ex-vessel price determination are considered endogenous.

Harvest in area T is dominated by the behavior of individual fishermen and their responses to three factors: 1) estimated stock conditions, 2) revenue expectations, and 3) regulatory actions of the ADF&G. Development of a suitable analytical framework requires that all three factors be included in the harvest submodel.

A number of authors have discussed various approaches to modeling total harvest (see Bell 1972; Clark 1985; Clayden 1972; Hannesson 1983; Tomkins and Butlin 1975; Waugh 1984). The most commonly used approach was developed by Gordon (1954) and later revised by Schaefer (1957). The Gordon-Schaefer model relates total catch (QHARVEST) to the application of fishing effort (EFFORT) and abundance of the legally exploited population (BIOMASS).

$$QHARVEST = q \; EFFORT \; BIOMASS \qquad (1)$$

Total harvest is proportional to effort and fish biomass, with q being a catchability coefficient (assumed to be positive). This particular specification has its roots in fisheries biology and can be used to predict total harvest if one has estimates of catchable biomass and fishing effort.

Hannesson (1983) criticizes the harvest framework represented by Equation (1), arguing that it is an unnecessarily restrictive functional form, that assumes unitary output elasticities with respect to effort and biomass. Unitary output elasticities, in turn, imply constant returns to scale, that is, a combined 1% change in effort or biomass will lead to a 1% change in total harvest. There is little reason to presume that harvest will increase at the same, constant rate over the entire range of effort and biomass values.

Hannesson relaxed the unnecessarily restrictive assumption of unitary output elasticity by employing a more general Cobb-Douglas functional form.

$$QHARVEST = p\ EFFORT^{r}\ BIOMASS^{s} \qquad (2)$$

The catchability coefficient (q) implied by Equation (2) is a function of the three estimated parameters p, r, s and two explanatory variables.

$$q = p\ EFFORT^{r-1}\ BIOMASS^{s-1} \qquad (3)$$

If s is estimated to be less than 1.0, catchability is inversely related to BIOMASS. This implies that increases in biomass will lead to proportionately smaller growth in total catch. Conversely, if s exceeds 1.0, increasing returns can be expected with respect to fish abundance. The same general arguments apply to the EFFORT parameter (r). An r less than 1.0 would suggest that crowding externalities exist; increasing effort leads to crowding on the fishing grounds and smaller catches per unit effort.

Equation (2) provides a potential framework for predicting Bristol Bay king crab harvest ($QHARVT_t$) once measures of effort and the biomass of legally harvestable crab (LEGALS) are defined. Effort must be quantified by variables that represent homogeneous inputs to the production process given by Equation (2). The number of vessels used in a fishery is often employed to quantify total effort. However, fleet size is a poor measure of harvest effort in the southeastern Bering Sea king crab fishery: vessel configurations and size are heterogenous. The fleet includes recently constructed, highly specialized crab boats measuring at least 120 feet in length, as well as multipurpose salmon and halibut boats in the 50 to 75 foot class. Thus, fleet size reflects only the decision by vessel owners to participate in a fishery. It does not measure the intensity at which operators fish.

Effort may be quantified more effectively by measuring fishing intensity in the context of the harvest technique. For example, the number of potlifts made during a season measures actual fishing effort. Potlift activity represents a direct measure of fishing effort and, ceteris paribus, harvest. Alaska Department of Fish: and Game, regulations require that steel and nylon mesh pots be used to capture king crab. All pots are similar in design and represent relatively homogeneous production units. Each time a pot is retrieved from the ocean floor (i.e., a potlift), captured crab are removed from the population. Though pot availability, type of bait used, and soak time also influence harvest effort, industry-wide data on these factors are not available. Thus, potlift activity proxies for the basic production decision determining total catch and is the designated effort component of the hypothesized harvest function.

The other explanatory component to Equation (2) is biomass. There are two relevant dimensions to total biomass: the stock of legal crab (LEGALS) and the stock of nonlegal crab (NONLEGALS), which are derived in Matulich, Hanson and Mittelhammer (1988a).

$$LEGALS_t = (SIZELIM_t \; MALE8_t) + MALE914_t \tag{4}$$

$$NONLEGALS_t = (FEM514_t + MALE514_t) - LEGALS_t \tag{5}$$

Equation (4) defines an upper bound to potential harvest, while Equation (5) accounts for inefficiencies due to pot crowding and handling of crab that must be returned to the sea. Legal harvest can be expected to fall, ceteris paribus, as the stock of nonlegals rises. While potlift activity is a behavioral relationship (discussed in the next section), legal and nonlegal biomass are definitional identities that link the biological response submodel (Matulich, Hanson and Mittelhammer 1988a) to the harvest sector. The biomass identities also incorporate the influence of external policy regulation and management into the harvest relationship.

The estimated Bristol Bay harvest function is given in Equation (6). All variables are measured in million pounds. Weighted, nonlinear 2SLS was used to estimate $QHARVT_t$.

$$\underset{}{QHARVT_t} = \underset{(1.50)}{4.12996} \; \underset{(11.80)}{LEGALS_t^{1.06872}} \; \underset{(-3.69)}{NONLEGALS_t^{-0.35311}} \; \underset{(5.08)}{POTLIFTS_t^{0.55825}} \tag{6}$$

$R^2 = 0.9748$ df = 11

The statistical goodness of fit measures in conjunction with Figure 1 illustrate the predictive accuracy of Equation (6).[4/] Aside from a single minor turning point error in 1979, the estimated relationship is good.

Equation (6) allows rejection of the hypothesis that the effort output elasticity is unitary because 1.0 is not contained in the 95% confidence interval (0.31-0.81) estimated for the $POTLIFTS_t$ parameter. Thus, a 1% increase in potlifts can be expected to generate less than a 1% change in harvest. This inelastic response of total harvest to changes in potlift activity supports the hypothesis that effort exhibits decreasing returns to scale. Lack of resource mobility and the search and capture characteristics of the king crab fishery are likely contributors to this finding. Equation (6) also suggests that some pot crowding inefficiencies exist, as evident from the negative parameters on $NONLEGALS_t$

Alternative specifications that included $VESSELS_t$ as a proxy for effort conformed to the anticipated outcome. Inclusion of fleet size was statistically insignificant and generated poorer prediction of the historical data.

Though both legal and nonlegal biomass appear to be important explanatory components of the harvest equation, catch responds quite differently to changes in $LEGALS_t$ from that observed with $NONLEGALS_t$. In contrast to the effort component, one cannot reject the hypothesis that legal biomass exhibits constant returns. The 95% confidence interval on

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4/Statistical significance of the harvest function constant was based on the null hypothesis around 1.0. All other t-statistics reported for Equation (6) are based on the hypothesis that the i-th parameter estimate equals zero.

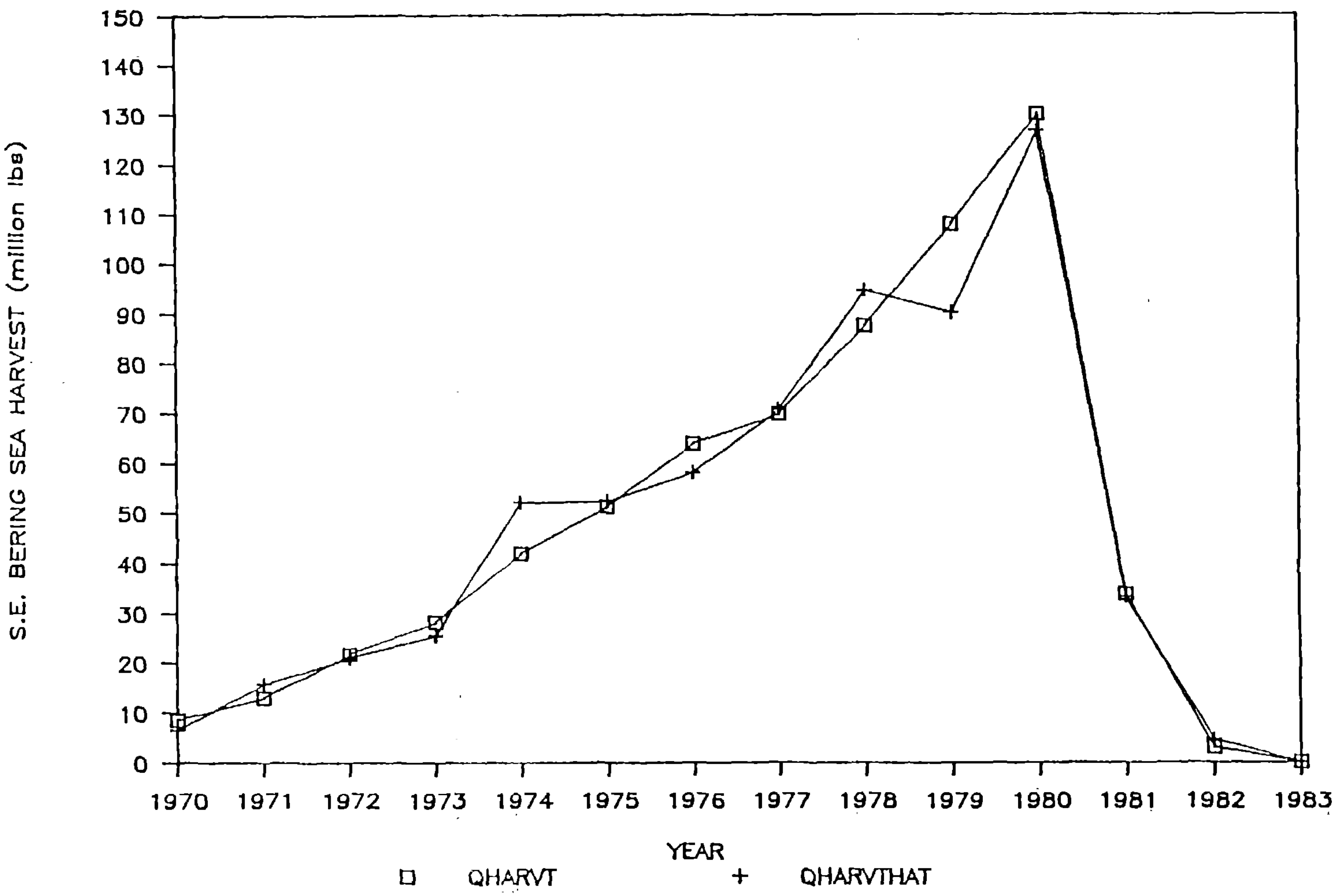

Figure 1.--Actual (QHARVT) versus predicted (QHARVTHAT) Southeastern Bering Sea harvest, 1970-83.

$LEGALS_t$ ranges from 0.86 to 1.27. The output elasticity with respect to legal abundance may be unitary. It is conceivable that a 1% change in legal biomass could result in a corresponding 1% variation in harvest. Nonlegal abundance is estimated to have a smaller and depressing impact on total harvest.

Effort: Bristol Bay Potlift Activity ($POTLIFTS_t$)

The principal behavioral decision of vessel operators, assuming they place pots where they expect to catch the most crab, is how many potlifts to make. Four factors are perceived to influence this number: 1) revenue expectations, 2) regulations directly controlling total catch, 3) competition from other vessels, and 4) estimated legal crab abundance. The potential role that each of these factors plays in formulating $POTLIFTS_t$ is discussed below.

Rising revenue expectations should stimulate increased potlift effort. Fishermen can form revenue expectations from two pieces of available information: anticipated total harvest and ex-vessel price. Prior to the season, ADF&G announces a harvest guideline that establishes upper and lower bounds on the expected seasonal catch based upon what management biologists feel is the appropriate level of resource exploitation. The GHL is not a quota, but rather, helps fishermen form and update their own catch expectations.

Ex-vessel prices, on the other hand, are known throughout the season. Prices are first negotiated prior to the start of each season. Fishing usually does not begin until a price is mutually agreed upon by processors and vessel operators. Price typically deviates from the negotiated starting value as the season progresses, but fishermen have fairly accurate knowledge of these price variations and can adjust their potlift effort accordingly.

Consequently, Bristol Bay revenue expectations are hypothesized to be the product of average Bristol Bay ex-vessel price paid per pound of raw crab in the current period ($EXPRT_t$) and the announced harvest guideline for area T measured in million pounds ($GUIDE_t$).

Two additional ADF&G management policies impact fishing effort: total season length ($DAYS_t$) and the relatively new policy of exclusive registration. $DAYS_t$ limits total effort by establishing season length through emergency closure. The closure announcement usually is made 1 week prior to termination of the season, thereby limiting cumulative seasonal potlifts. The policy of exclusive registration has a less direct but important impact on effort. It precludes vessel operators from switching to alternative king crab fisheries in response to higher ex-vessel prices or greater harvest opportunities.?' This institutional constraint minimizes the potential alterations in potlift activity once the season has commenced. Likewise, lack of coincidence between the king crab season and other fishing seasons deters movement of capital stock, and thus effort, to other fisheries.

Fleet size ($VESSELS_t$) determines both the number of fishing units making potlifts and the degree of competition that is perceived to exist among fishermen. Competition from other vessels in this open access fishery may induce vessel operators to increase potlift effort. Fishermen confronted by a harvest guideline that bounds total catch recognize that their success depends upon their own effort and the effort of all other

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5/ Area Q in the northern/western Bering Sea and area R around Adak Island are the only exceptions to exclusive registration.

crews harvesting crab. Expanding fleet size intensifies this sense of competition and stimulates increased potlift activity per vessel.

The final, and perhaps most influential factor determining $POTLIFTS_t$ is the estimated abundance of legally harvestable crab ($LEGALS_t$). Legal biomass is expected to be inversely proportional to potlift effort because catch per potlift should be higher. With higher CPUE, total effort can fall, assuming all other variables are held constant.

One might expect that harvest operating costs and opportunities in other fisheries also impact total potlift effort in Bristol Bay. Both factors, however, primarily influence fleet size rather than the number of potlifts. Vessel operating expenses are dominated by fuel costs because crew shares typically are paid a percentage of the vessel's gross receipts, less food costs. The relationship between fuel consumption and the number of potlifts is unclear and should have only minor impact on total potlift effort.

Each of the four principal factors--revenue expectations, fleet size, season length, and abundance of legal crab--were combined in a Cobb-Douglas functional form to predict fishing effort. no-stage, nonlinear least squares was used to estimate the $POTLIFTS_t$ relationship in Equation (7).

$$POTLIFTS_t = \underset{(10.69)}{0.001001} \left[(EXPRT_t\ GUIDE_t)^{\underset{(5.03)}{0.37371}} (VESSELS_t)^{\underset{(5.69)}{0.76095}} (DAYS_t)^{\underset{(3.80)}{0.29166}} (LEGALS_t)^{\underset{(-2.22)}{-0.12653}} \right] \underset{(-4.74)}{-0.18699}\ IND79 \qquad (7)$$

$R^2 = 0.9813$ $\qquad$ df = 9

The statistical goodness of fit measures and Figure 2 illustrate the predictive accuracy and overall significance of Equation (7) for the period from 1970 to 1983.[6/] An additive indicator variable (IND79) was included to remove the influence of the 1979 observation on $POTLIFTS_t$. This observation appears to be an outlier; it is almost 25% less than the 1978 estimate despite the 20 million pound increase in Bristol Bay harvest.

The exponents associated with each of the explanatory variables represent factor elasticities (i.e., the responsiveness of potlift effort to changes in the given factor).[7/] While all four elasticities are less than 1.0, the statistical evidence indicates effort responds somewhat to changes in these factors. For example, a 1% change in composite revenue expectations (or ex-vessel price) is estimated to induce a 0.37% change in total potlifts. This result implies that once the decision is made to participate in the king crab fishery, rising price expectations provide a modest impetus for vessel operators to increase effort.

Bristol Bay Fleet Size ($VESSELS_t$)

Although the southeastern Bering Sea was not an exclusive registration area prior to 1980, this policy was employed in six other areas which had a secondary effect of requiring Bristol Bay fishermen to decide where the) would fish before the harvest season opened. Preseason information and

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6/The t-statistic for the parameter premultiplying revenue expectations tests the null hypothesis around 0.01. All other t-statistics refer to tests around zero.

7/Interpretation of elasticities in a simultaneous equation represent "first-round effects" that assume all other simultaneously determined right-hand side variables remain unchanged.

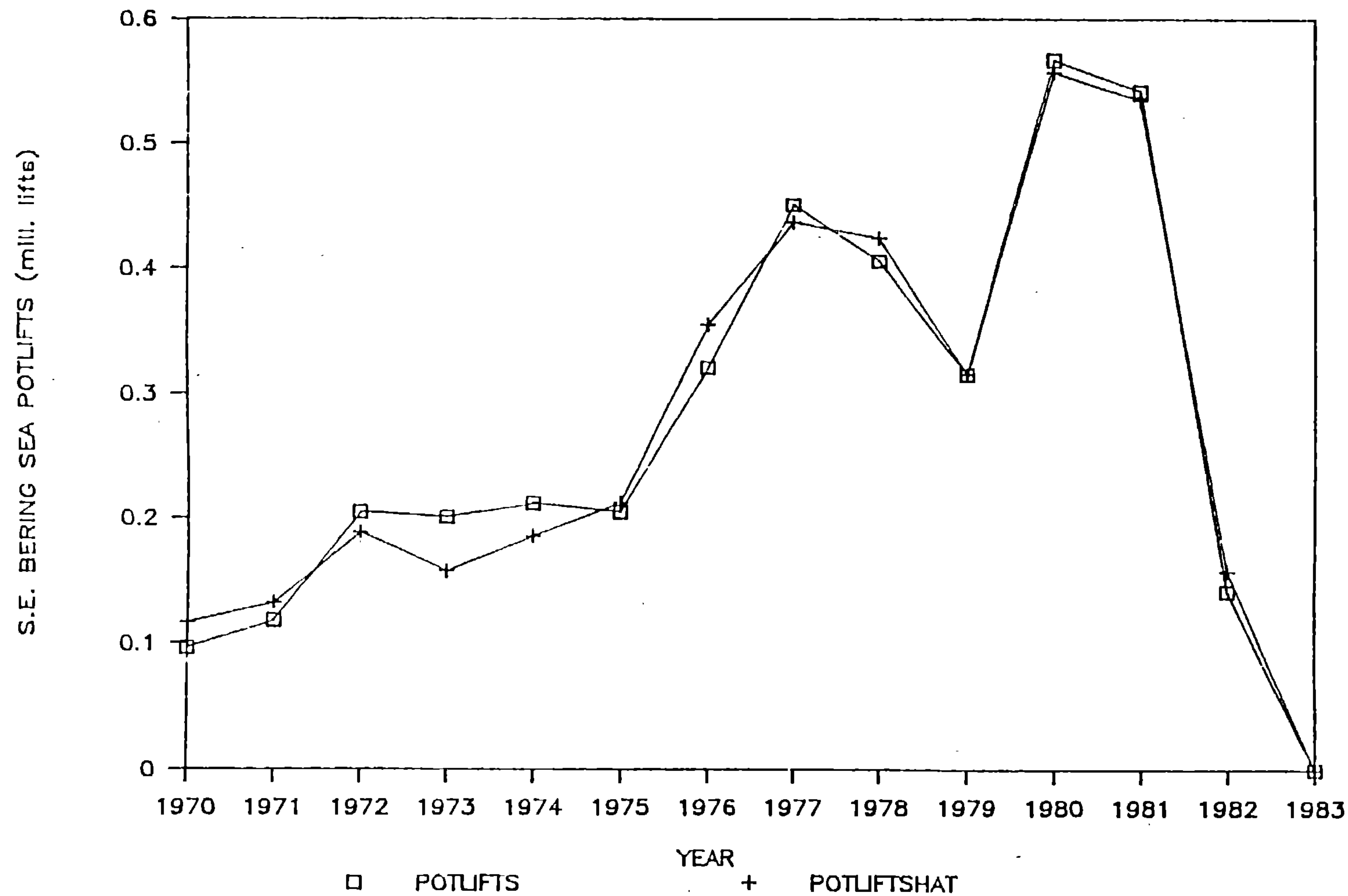

Figure 2.--Actual (POTLIFTS) versus predicted (POTLIFTSHAT) Southeastern Bering Sea potlifts, 1970-83.

expectations are fundamental to any decision regarding where to fish. In most cases, this information can be derived from fishery area performance characteristics during the preceding season.

Four factors are perceived to influence owner behavior and the resulting Bristol Bay fleet size during the current period ($VESSELS_t$): 1) area T harvest revenue expectations, 2) anticipated revenues in the alternative harvest areas (area W), 3) estimated legal king crab biomass, and 4) the existing vessel stock. Each of these factors are premised upon profit maximizing behavior of vessel owners and operators.

Foremost in the minds of owners is the revenue potential of the fishery. If revenue expectations are high, owners will be motivated to register for the Bristol Bay fishery. Conversely, if the fishery has a poor outlook, fleet size probably will be small in comparison. Since vessel owners cannot use current ex-vessel prices to form this expectation, they must extrapolate from the past. It is hypothesized that price expectations are formed from the average ex-vessel price observed in the previous period ($EXPRT_{t-1}$). Harvest expectations, on the other hand, can be formed from two sources. The harvest guideline ($GUIDE_t$) provides an obvious measure of anticipated harvest because it represents an advisory limit on total catch that is known before fishing begins. Harvest expectations also can depend on total catch from the previous season ($QHARVT_{t-1}$). Choice of the better revenue expectation measure is an empirical question. Two different revenue expectation frameworks are hypothesized: 1) a one-period lag on actual Bristol Bay revenues ($REVT_{t-1}$), that is, the product of $EXPRT_{t-1}$ and $QHARVT_{t-1}$; and 2) an expectation based on the harvest guideline and lagged ex-vessel price ($GUIDE_t$ $EXPRT_{t-1}$).

Opportunities in other fisheries, particularly alternative king crab harvest areas, can influence fleet size in area T. Revenue expectations for the other areas, as measured by total revenues during the previous season in area W ($REVW_{t-1}$), should be inversely related to the current number of vessels participating in the Bristol Bay fishery. Lagged harvest ($QHARVM_{t-1}$) times lagged average ex-vessel price ($EXPRW_{t-1}$) was the only revenue expectation considered for area W, since a guideline historically has not been established in some portions of area W. All revenue variables are measured in millions of dollars.

Legal king crab abundance ($LEGALS_t$) provides vessel owners with information on harvest potential for the upcoming season. Increasing legal abundance is expected to stimulate more vessel owners to operate in Bristol Bay, thereby producing a larger king crab fleet. However, $LEGALS_t$ and $GUIDE_t$ cannot be specified in the same equation because the guideline is formed as a linear combination of legal biomass.

The final factor that conceptually influences fleet size is the existing vessel stock. Crab boats, particularly those used in area T (capitalized values averaged between $1.5 and $3.0 million in 1980), have limited alternative uses. It appears that most owners operate their boats provided they can cover variable costs with harvest receipts. Fleet size in the previous period ($VESSELS_{t-1}$) is hypothesized as adequate to track this resource fixity.

Alternative specifications of Equation (8) were estimated to predict Bristol Bay fleet size. The semilog variant given in Equation (8) produced the best overall results. Weighted, nonlinear least squares was used to estimate the relationship which is a function of strictly predetermined variables, and thus, segmentable from the jointly endogenous components of the harvest and derived demand submodels.

$$VESSELS_t = e^{(3.77003 + 0.00602\ EXPRT_{t-1}\ QHARVT_{t-1} + 0.00318\ LEGALS_t + 0.00212\ VESSELS_{t-1} - 10.35191\ IND83)} \quad (8)$$

(37.88) (3.37) (5.88) (2.01) (-0.03)

$R^2 = 0.9957$ $\quad$ df = 9

The statistical goodness of fit measures and Figure 3 illustrate the overall accuracy and significance of the estimated $VESSELS_t$ relationship for the period from 1970 to 1983, with IND83 marking fishery closure.

Revenue expectations from area W were included in the initial estimation of Equation (8) but lacked statistical significance. It appears that revenue expectations in other areas have been relatively unimportant in influencing fleet size in area T. This undoubtedly stems from highly productive and profitable conditions that were experienced in the Bristol Bay fishery during the 1970s. Attempts to incorporate the variable costs, measured by average diesel fuel prices, also were unsuccessful.

Equation (8) documents that there is some structural inflexibility associated with the area T king crab fleet. Elasticity calculations reveal that fleet size is only modestly unresponsive to changes in explanatory variable levels. For example, the elasticity of fleet size with respect to revenue expectations ranges from 0 to 0.704 over the historically observed levels of $REVT_{t-1}$ (0 to \$116.95). A 1% change even in the record revenue expectation is predicted to produce only a 0.704% change in fleet size.

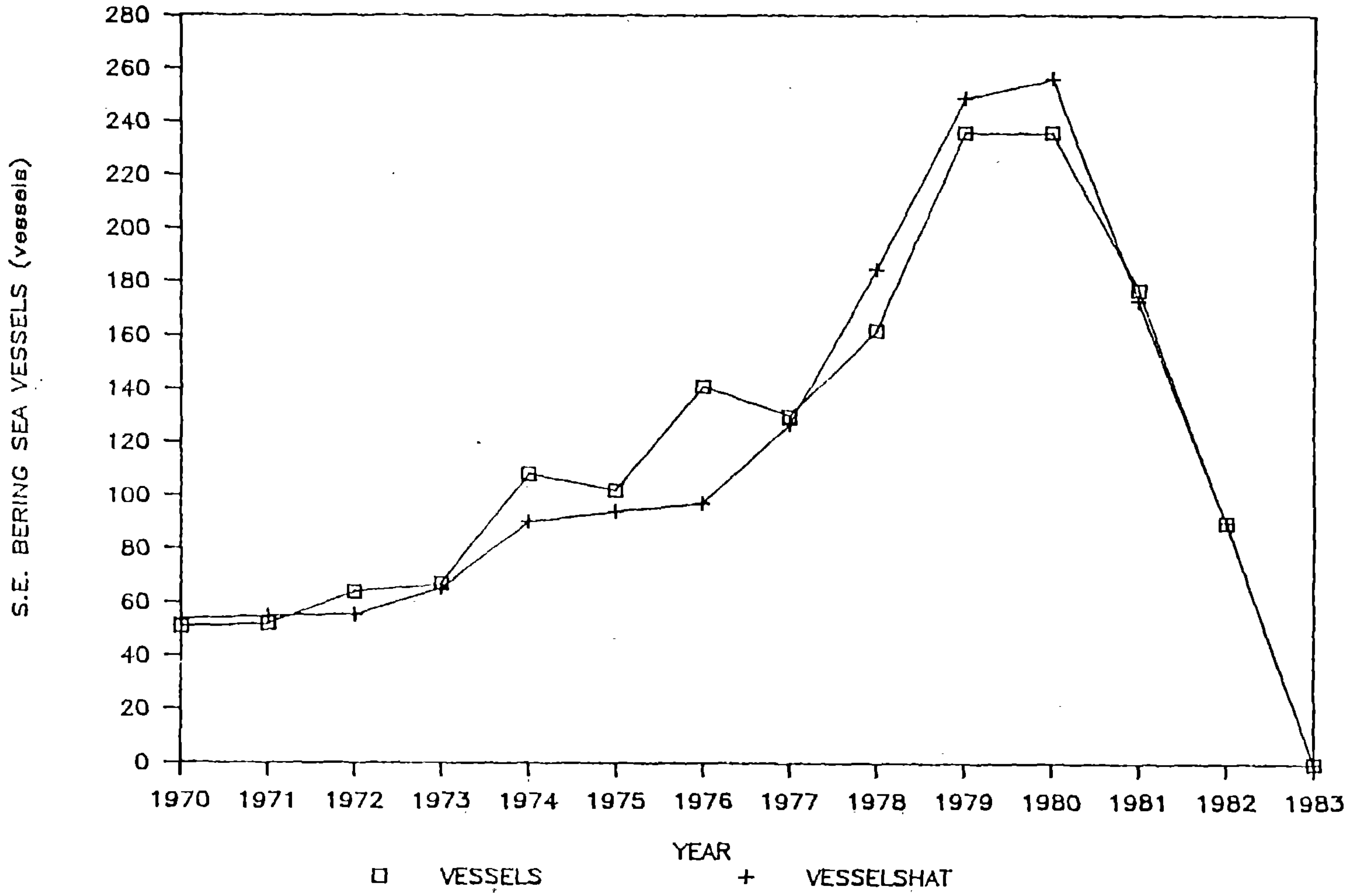

Figure 3.--Actual (VESSELS) versus predicted (VESSELSHAT) Southeastern Bering Sea crab fleet size, 1970-83.

Similarly, the elasticities of fleet size with respect to $LEGALS_t$ and $VESSELS_{t-1}$ have ranges of 0.013 to 0.755 and 0 to 0.500, respectively. Relative asset fixity, limited knowledge/experience in alternative fishing grounds, relative abundance of crab stocks in area T, and exclusive registration policies in this and other areas are possible contributing factors to the inelastic responses.

Harvest Sector Definitional Identities

Several additional identities complete the specification of the harvest sector. These equations define harvest from all other areas, total industry harvest, effort efficiency, and two measures of harvest congestion. The information provided by these identities can be used in explaining other aspects of market behavior.

Absence of trawl survey data in areas outside of Bristol Bay requires modeling harvest from all other areas (QHARVWt), as the residual difference between total processed production and the harvest generated from area T.

$$QHARVW_t = (SECTPROD_t + MEATPROD_t) - QHARVT_t \tag{9}$$

Equation (9) ultimately is linked to the product market via $SECTPROD_t$ and $MEATPROD_t$ (see discussion on derived supply).

Total U.S. harvest of king crab ($QHARVUS_t$) is defined as the sum of $QHARVT_t$ and the aggregate catch from all other fishing areas ($QHARVW_t$).

$$QHARVUS_t = QHARVT_t + QHARVW_t \tag{10}$$

Effort efficiency typically is quantified by a CPUE measure. In this case, the efficiency of harvest effort employed in the Bristol Bay fishery can be defined by the legal biomass caught per potlift, that is, weight per unit effort ($WPUE_t$), measured in pounds per potlift.

$$WPUE_t = QHARVT_t \;/\; POTLIFTS_t \qquad (11)$$

Harvest congestion can influence both vessel and processing plant efficiency, and ultimately can affect wholesale price formation (see derived demand section). The average quantity harvested per day in Bristol Bay ($QHTDAY_t$) is a relative measure of fleet efficiency and daily fishing success. Derivation of $QHTDAY_t$ is given by the ratio of $QHARVT_t$ and regulated season length in area T ($DAYS_t$). The ratio is calibrated in thousand pounds per day.

$$QHTDAY_t = (QHARVT_t \;/\; DAYS_t)\; 1000 \qquad (12)$$

The information provided by Equation (12) also can be used to determine the degree of dockside congestion occurring at processing facilities ($PLANTS_t$). $QHTDAY_t$ can be combined with the quantity caught per day in all other harvest areas ($QHWDAY_t$) to measure this congestion:[8/] The weighted average quantity harvested per day per plant for the entire industry ($QHARDP_t$) reflects the crowding that occurs as vessels unload their catches at processing facilities. This relationship is given by Equation (13).

$$QHARDP_t = \frac{(QHARVT_t \; QHTDAY_t)}{QHARVUS_t} \;/\; PLANTS_t + \frac{(QHARVW_t \; QHWDAY_t)}{QHARVUS_t} \;/\; PLANTS_t \qquad (13)$$

[8/] $QHWDAY_t$ was calculated as a weighted average of the harvest per day from each are. It had to be treated exogenously because a meaningful aggregate season length for all other areas could not be derived.

$QHARDP_t$ is weighted by the harvest from each area and is measured in thousand pounds per day per plant.

DERIVED DEMAND: PROCESSOR DEMAND FOR HARVESTED KING CRAB

Rx-vessel Price ($EXPRT_t$)

A seasonal average ex-vessel price offer function links processing and, ultimately, wholesale market demands with the harvest of Alaskan king crab. The market for raw king crab resembles that of a bilateral monopoly. Processors have a derived demand for raw crab and consider traditional factors of demand (i.e., expected wholesale king crab product prices, total harvest, export market prices, foreign currency exchange- rates, and processing costs) in offering an ex-vessel price to fishermen. However, processors also consider harvest costs and fishing success rates in establishing the negotiated preseason starting price and intraseasonal ex-vessel price adjustments (Hanson and Matulich 1986).[9]/

The wholesale price that processors expect to receive for their output clearly should have a strong positive influence on what they are willing to offer fishermen for harvested king crab. Processors conceptually can form

---

9/Vessel owners and operators initiate the negotiation process (typically through established fishermen's organizations) by soliciting ex-vessel price offers from each of the established processing firms. These individual offers then are evaluated collectively by the fishermen. If an acceptable offer is received, that firm(s) is contacted and arrangements are made to begin fishing. All other firms also are informed of the agreed- upon price and tend to offer the same amount. If none of the offers are deemed acceptable, the process is repeated until a settlement can be reached. Processors also may form informal bargaining groups in negotiating ex-vessel prices.

an expectation based on the weighted average of wholesale section and meat prices observed during the previous marketing period ($WTAVP_{t-i}$). Increased $WTAVP_{t-1}$ should stimulate processors to offer fishermen correspondingly higher ex-vessel prices.

Conversely, increased harvest levels in Bristol Bay ($QHARVT_t$) should reduce the ex-vessel price offered to fishermen as larger supplies tend to depress wholesale market prices. Although processors use an expectation of harvest based on historical data or estimated legal crab abundance to develop the initial preseason offer, actual weekly catch statistics for the current period can be used to evaluate and modify ex-vessel prices once the season begins. Seasonal harvest ($QHARVT_t$), which technically is not known until season closure, serves as an approximation of these weekly harvest data in forming the impact of current harvest on the seasonal average ex-vessel price offered by processors.

Japanese consumers have been the largest importers of U.S. king crab products since 1974, when the United States negotiated closure of the eastern Bering Sea fishery to the Japanese. The resulting enlarged export market for U.S. king crab products caused processors to revise their pricing behavior. Japanese exchange rates and market conditions suddenly became influential in the establishment of Bristol Bay ex-vessel prices. Rising exchange rates ($EXCH_t$), measured in $/yen, make U.S. king crab products relatively less expensive for Japanese consumers, and tend to stimulate growth in crab exports to Japan. This growth increases primary demand facing the industry, which in turn causes the average domestic wholesale price to increase. The expectation of higher wholesale product prices induces processors to raise their ex-vessel price offer to fishermen.

Unfortunately, attempts to incorporate $EXCH_t$ in primary demand equations met with wrong signs and, thus, was omitted as an explanatory variable. Additional research is needed to incorporate this aspect of market behavior.

Processing costs are inversely related to the price that processors offer to fishermen. Increased processing costs induce processors to reduce crab input costs by lowering their ex-vessel price offer to fishermen (assuming constant wholesale prices). Hanson and Matulich (1986) found that processors consider interest rates to be the most influential processing cost factor in the establishment of ex-vessel prices within this capital intensive industry.. The third quarter prime rate reported by the U.S. Federal Reserve ($INTR_t$) is used here to account for processing costs in the ex-vessel price offer function.

Although demand theory suggests that processors should be insensitive to costs incurred by factor input suppliers, experience in the king crab industry reveals that they do account for harvest costs in their ex-vessel price offer to fishermen. Processors recognize that ex-vessel prices must provide fishermen with sufficient revenue potential to cover vessel operating costs. Since diesel fuel is the primary variable input used by vessel operators during the harvest season, an average seasonal diesel fuel price in dollars per gallon ($FUEL_t$) is included in the hypothesized $EXPRT_t$ framework.[10]/

10/Incomplete time series data were available on fuel prices paid by fishermen in Alaska. An alternative that follows the same trend is the average monthly price paid per gallon for diesel fuel in Washington (U.S.D.A., Agricultural Statistics, various years). These monthly averages are used to derive a seasonal average value (July to June).

Another factor cost apparently considered by processors is effective fishing effort. Potlift success rate can be measured by the weight of legal sized crab caught per potlift ($WPUE_t$). As $WPUE_t$ increases, fewer potlifts are required to achieve the same harvest and fishing effort efficiency rises. This increased efficiency leads to lower vessel operating costs and provides processors with an incentive to decrease their ex-vessel price offer. Consequently, $WPUE_t$ is included in the ex-vessel price offer function to reflect this inverse relationship between effort efficiency and ex-vessel prices. Current $WPUE_t$ can be used rather than some expectation because it can be estimated by processors and fishermen during the season.

The ex-vessel price offer function is specified in Equation (14).

$$
\begin{aligned}
EXPRT_t = \; & \underset{(-1.705)}{-0.34479} + \underset{(9.856)}{0.52485}\, WTAVP_{t-1} - \underset{(-3.249)}{0.01075}\, QHARVT_t \\
& - \underset{(-4.515)}{11.91756}\, INTR_t + \underset{(4.857)}{1.96136}\, FUEL_t - \underset{(-0.312)}{0.00039}\, WPUE_t - \underset{(-14.356)}{5.30270}\, IND83 \qquad (14)
\end{aligned}
$$

$R^2 = 0.9809 \qquad df = 7$

Two-stage least squares was used to estimate this relation because EXPRT is simultaneously determined with $QHARVT_t$ and $POTLIFTS_t$ (i.e., $WPUE_t$). Figure 4 and the statistical goodness of fit measures highlight the overall accuracy and significance of the estimated processor ex-vessel price function for the period from 1970 to 1983.

$WPUE_t$ was retained in the $EXPRT_t$ relationship despite its low t-value (presumably caused by colinearity with $QHARVT_t$) because processors reported it to be an important depressing influence on ex-vessel prices. It also seemed to improve the prediction accuracy of the estimated equation.

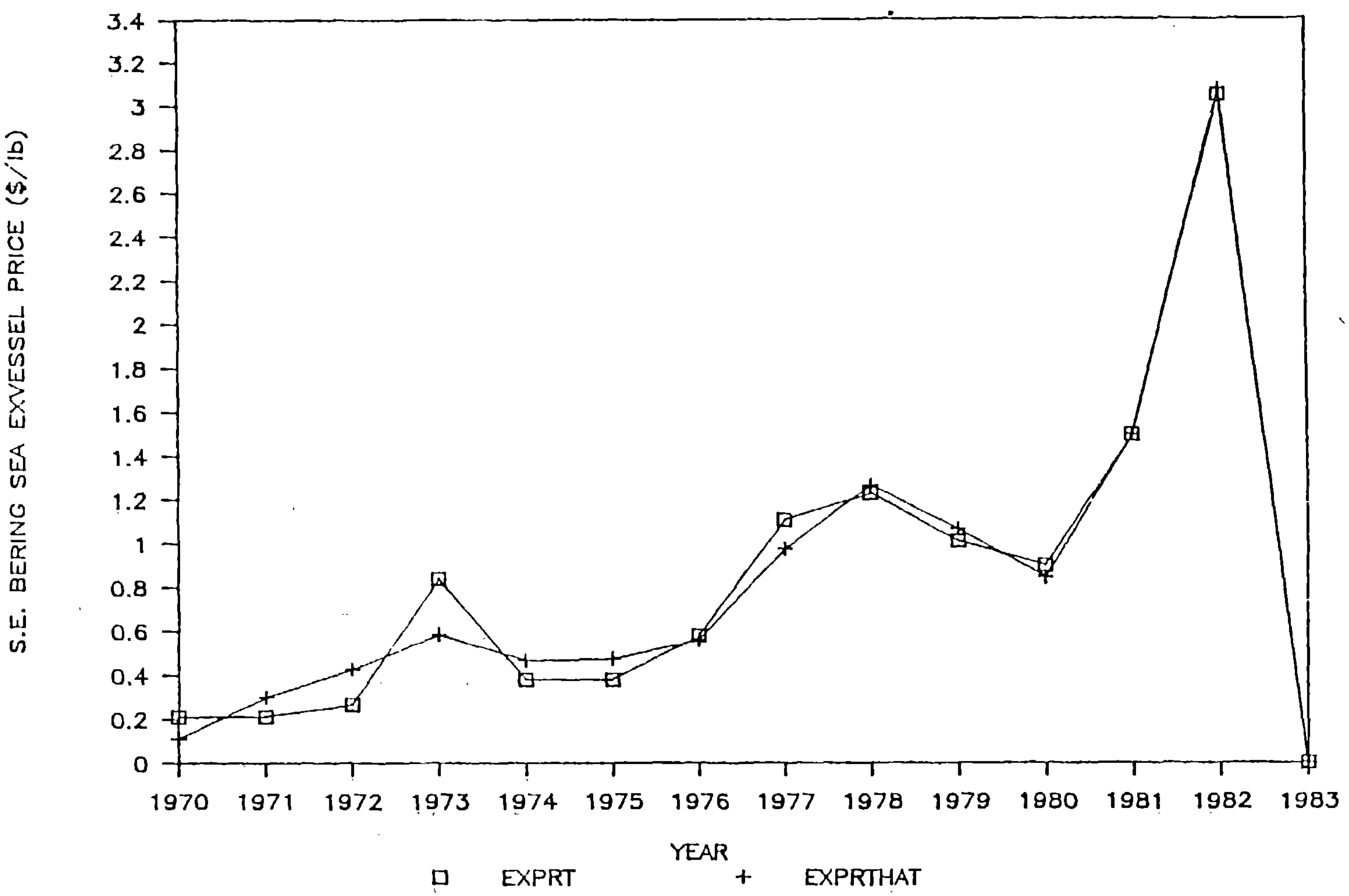

Figure Lt.--Actual (EXPRT) versus predicted (EXPRTHAT) Southeastern Bering Sea seasonal average ex-vessel price for red king crab, 1970-83.

An indicator variable (IND83) was included to account for the structural break caused by closure of the Bristol Bay fishery in 1983. This one-period closure eliminated Bristol Bay ex-vessel price formation.

First-round ex-vessel price elasticities given in Table 1 show that processors generally are less responsive to changing conditions when harvests are low. LOW harvests correspond to such high ex-vessel prices that in upward price adjustment is restricted--very low harvests effectively signal a price cap. As harvest increases, however, so too does processor sensitivity to variation in the explanatory variables.

Perhaps the most notable exception to this statement concerns processor response to changing wholesale price expectations, which are elastic across a broad spectrum of harvest levels. Ex-vessel price offers to fishermen are quite sensitive to changing wholesale price expectations in this highly valued, but historically volatile fishery.

The ex-vessel price response to incremental changes in total catch is inelastic except at high harvest levels when there are apparent surpluses of harvested crab. This result has important revenue implications for fishermen and policymakers alike. Harvests at too high a level actually can decrease current revenues to fishermen. Lowering harvests under high stock conditions holds the potential of larger aggregate revenues for fishermen. This finding highlights the importance of managing the fishery with attention to feedback effects between biological stock conditions and economic consequences of those conditions. Liberal harvest policies are not necessarily in the best economic interest of fishermen.

At low catch levels, processors are relatively unresponsive to changing interest rates in formulating their ex-vessel price offer to fishermen. Ex-vessel prices change proportionately less than processing costs as

Table 1.--Estimated elasticities for the ex-vessel price offer relationship.

Associated explanatory variable (X_{it})	Estimated elasticities: Low $QHARVT_t$ (1982)[a]	Mean values[b]	High $QHARVT_t$ (1980)[c]
$WTAVP_{t-1}$	1.074	2.632	2.411
$QHARVT_t$	-0.011	-0.609	-1.652
$INTR_t$	-0.630	-1.427	-1.618
$FUEL_t$	0.681	1.344	2.373
$WPUE_t$	-0.003	-0.071	-0.106

[a]The ratio of the explanatory variable (X_{it}) and predicted $EXPRT_t$ was derived from the 1982 observation. This corresponds to the lowest, positive Bristol Bay king crab harvest since the mid-1960s.

[b]Mean values for all variables were used to predict $EXPRT_t$ and formulate the ratio between X_{it} and $\hat{EXPRT}_t$.

[c]The ratio between X_{it} and $\hat{EXPRT}_t$ was derived from the 1980 observation--the year corresponding to the largest recorded king crab harvest in Bristol Bay.

processors attempt to maintain sufficient crab input supplies under limited harvest conditions. Conversely, ex-vessel price response to changing interest rates becomes elastic at or above mean harvest levels. This result seems to suggest that minimizing processing costs becomes at least as important as maintaining crab throughput.

Finally, processors generally are responsive to changing fuel prices, but insensitive to alterations in the potlift success rate. The generally elastic response of processors to changing fuel costs underscores the bilateral monopolistic character of this offer relationship; processors are sensitive to the principal factor input for fishermen. The inelastic response to changes in $WPUE_t$ does conform to prior expectations but is consistent with the lack of significance encountered in the ex-vessel price offer function, Equation (14).

Derived Demand Definitional Identity

$EXPRT_t$ can be combined with the exogenously determined aggregate average ex-vessel price for all other harvest areas ($EXPRW_t$) to derive the industry average ex-vessel price ($AVEXPR_t$). Seasonal averages for the two areas (i.e., $EXPRT_t$ and $EXPRW_t$) are weighted by their respective harvests to quantify $AVEXPR_t$. All ex-vessel prices are measured in dollars per pound.

$$AVEXPR_t = \frac{(EXPRT_t \; QHARVT_t)}{QHARVUS_t} + \frac{(EXPRW_t \; QHARVW_t)}{QHARVUS_t} \qquad (15)$$

This industry average ex-vessel price links state-wide harvest with production and consumption in the composite system of equations.

DERIVED SUPPLY: THE ROLE OF PROCESSORS AND COLD STORAGE OPERATORS IN SUPPLYING KING CRAB PRODUCTS

Unlike the harvest and derived demand submodels, which concentrate on the Bristol Bay fishery, derived supply is modeled for the entire domestic industry.. A small amount of crab was imported ($SECTIMP_t$) from the U.S.S.R. during the 1968-83 period, but lack of data and relative unimportance of this supply source warranted treating $SECTIMP_t$ as exogenous. Market supply is focused on a single processed product form, frozen king crab sections. While king crab meat was the dominant product form prior to 1975, widespread adoption of brine freezing technology pushed sections into the principal product form. Meats are sold primarily to small, specialty and gourmet food outlets catering to a limited segment of total demand. Industry representatives expect this trend to continue and doubt there will be any significant production of extracted meats in the future. Consequently, meat production (and hence, meat supply) is treated as an exogenous variable and accounted for in the market clearing identity given by Equation (9).

Frozen king crab sections are marketed on a year-round basis, even though domestic section production coincides with the fishing season, which normally is less than a 3-4 month period each autumn. Domestic production and the exogenous imports represent the only addition to total supply for the entire marketing year (1 July-30 June). Thus, suppliers have transaction demands for frozen product inventories so that they can satisfy off-season primary demand. This transaction demand conceivably is directly proportional to total production of frozen sections in the current period ($SECTPROD_t$) In addition, processors have speculative motives for holding some stocks in an inventory.

Domestic supply of frozen king crab sections ($SECTSUP_t$) is provided from two sources: 1) direct marketing of domestically processed sections and 2) distribution of frozen sections being held in cold storage. Domestic firms reveal their willingness to supply sections by offering a price to wholesalers ($PSECT_t$). This wholesale price offer evokes a demand response which ultimately determines the quantity of sections that processors are able to sell to the market at the stated price offer. The wholesale price offer function embodies the derived supply relationship characterizing this industry.

Domestic production of frozen sections ($SECTPROD_t$) is modeled as a market clearing identity which enforces the equilibrium between quantity demanded and quantity supplied by these firms. The ending stock of frozen sections in storage ($SECTHOLD_t$) is formulated as a behavioral relationship. Although cold storage holdings are a source of derived supplies, they also represent an intermediate, short-term demand for frozen stocks and are treated in a demand framework.

The remaining endogenous components of derived supply are total domestic section supply ($SECTSUP_t$), the wholesale price of processed meats ($PMEAT_t$), and the weighted average of both section and meat wholesale prices ($WTAVP_t$). $SECTSUP_t$ is formulated as an accounting identity. $PMEAT_t$ is hypothesized to be in margin relationship with $PSECT_t$ which requires statistical estimation. $WTAVP_t$ also is structured as an accounting identity. The three behavioral relationships are presented first, followed by the three identities.

Wholesale Section Price ($PSECT_t$)

It is assumed that all suppliers attempt to maximize profits in competitive domestic and foreign markets subject to available technologies and entrepreneurial abilities. Economic theory suggests that the price offered by suppliers to wholesale markets conceptually depends on three factors: 1) available product supply (both in production and storage), 2) the cost of supplying sections to the market, and 3) wholesale price expectations.

Following the law of supply, one can expect a positive relationship between $PSECT_t$ and $SECTSUP_t$. Processors must be compensated to forego speculative opportunities associated with holding stocks.

There are two dominant categories of supply costs in this industry: production expenses and the opportunity cost of storing frozen product. Processors report that the purchase of raw crab is the primary expense in producing frozen crab sections (Hanson and Matulich 1986). The weighted average ex-vessel price for all harvest areas ($AVEXPR_t$) reflects one aspect of this expense. Rising ex-vessel prices will make processed frozen sections relatively more expensive to produce and motivate suppliers to increase their wholesale price offer. Similarly, falling $AVEXPR_t$ should generate, lower wholesale prices.

Another potentially important production expense is the level of plant utilization. If the plant is operating at or near capacity, the unit cost of processing is lower than if there is excess capacity. Efficient use of plant resources, therefore, leads to reduced price offers. Though plant utilization data are not available, the quantity harvested per day per plant ($QHAPDP_t$) can be used as a proxy for plant utilization efficiencies. Increasing $QHARDP_t$ should signal an increase in plant efficiency, and thus a decline in $PSECT_t$.

The opportunity cost of holding frozen sections in storage appears to be the most important monetary factor influencing product flow from inventory holdings. The prime interest rate ($INTR_t$) is a relative measure of this cost. The opportunity cost of holding stock expands as interest rate rises. This expansion stimulates suppliers to reduce inventories. Suppliers must lower their wholesale price offer in order to entice consumers to purchase these unwanted stocks. Therefore, $INTR_t$ should be inversely related to $PSECT_t$.

Wholesale price expectations based on recent pricing history can serve as a benchmark when establishing a price offer for the current period. One would expect an increase in $PSECT_{t-1}$ to prompt a proportionate rise in $PSECT_t$.

The estimated $PSECT_t$ relationship is given by Equation (16).

$$PSECT_t = \underset{(4.193)}{1.18130} + \underset{(1.872)}{0.01646}\, SECTSUP_t + \underset{(1.227)}{1.93266}\, AVEXPR_t$$

$$- \underset{(-0.916)}{0.06724}\, QHARDP_t - \underset{(-0.753)}{5.16925}\, INTR_t + \underset{(0.391)}{0.21348}\, PSECT_{t-1} \qquad (16)$$

$R^2 = 0.9726 \qquad df = 8$

Two-stage least squares was used to estimate Equation (16) because $PSECT_t$ is jointly endogenous with $PMEAT_t$, $SECTHOLD_t$, and $SECTCONS_t$. The regression was weighted by the squared reciprocal of lagged section price to correct for heteroskedasticity.

The statistical goodness of fit measures and Figure 5 indicate the significance and accuracy of the estimated processor wholesale price offer relationship for the period 1970-83. Though four of the explanatory variables (i.e., $AVEXPR_t$, $QHARDP_t$, $INTR_t$, and $PSECT_{t-1}$) had low estimated t-values, each was judged to have sufficient economic importance in

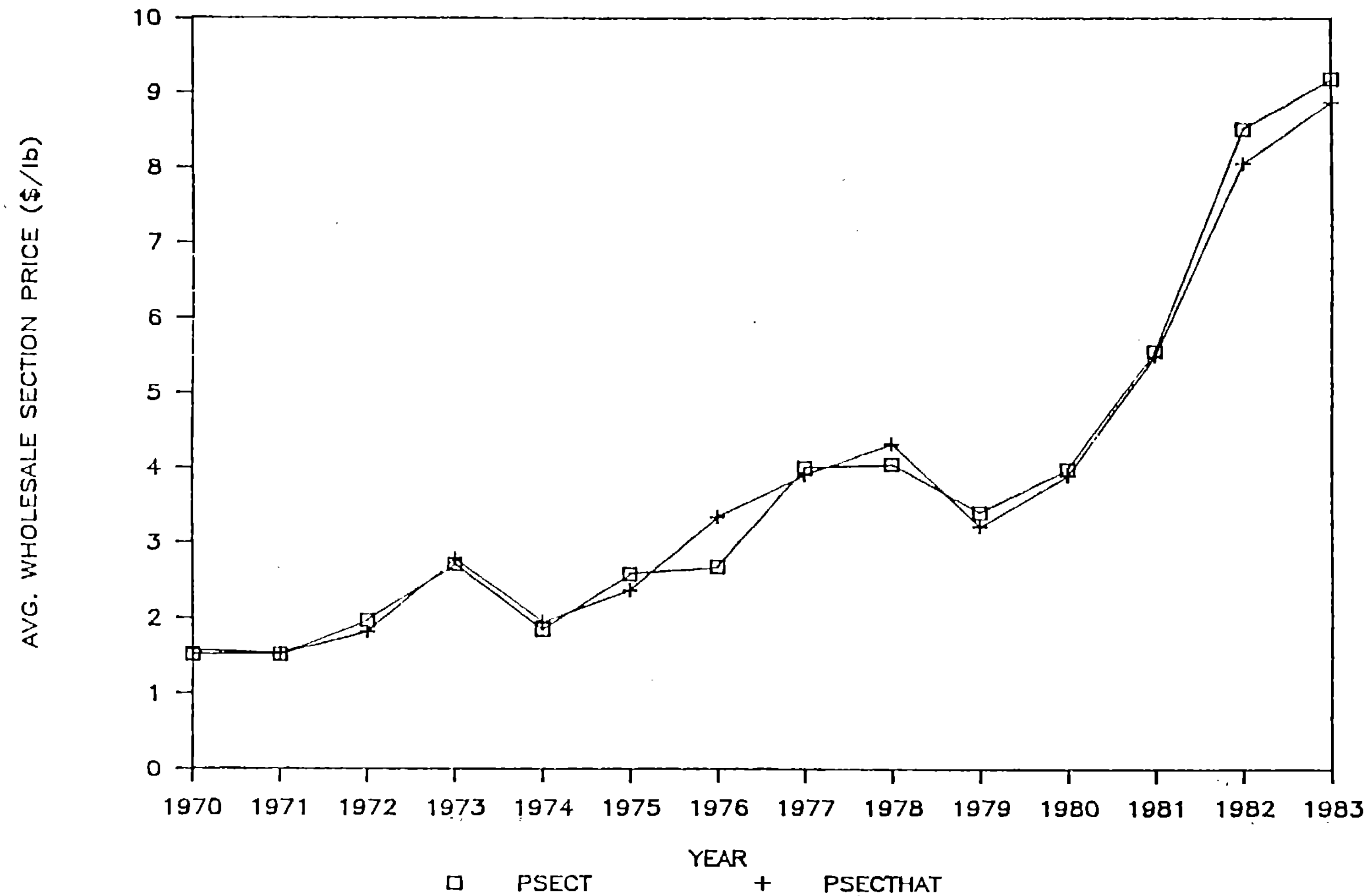

Figure 5.--Actual (PSECT) versus predicted (PSECTHAT) seasonal average New York wholesale market price for frozen king crab sections, 1970-83.

explaining supplier behavior to be retained in the final relationship.[11] Multicollinearity between the explanatory variables (three of which are endogenous) may account for the poor t-test results.

Price elasticity coefficients that measure the responsiveness of the wholesale offer price to changing conditions are listed in Table 2. In all cases, the wholesale offer price is estimated to be relatively inflexible (unresponsive) despite changing conditions.

Wholesale Meat Offer Price ($PMEAT_t$)

The wholesale offer price for king crab meats is perceived by processors to deviate from- section prices only by some proportion of the added labor required to extract the meat. Thus, $PMEAT_t$ was estimated as a margin relationship dependent on $PSECT_t$ and the wage rate for food and kindred products workers in Alaska ($LABOR_t$).

$$PMEAT_t = \underset{(-2.169)}{-1.77354} + \underset{(7.536)}{2.03793}\, PSECT_t + \underset{(1.038)}{0.28495}\, LABOR_t \qquad (17)$$

$R^2 = 0.9704$ df = 12

Equation (17) was estimated using 2SLS because $PMEAT_t$ was simultaneously determined with $PSECT_t$, $SECTHOLD_t$, and $SECTCONS_t$, The regression was weighted by $(PMEAT_{t-1})^{-2}$ to correct for heteroskedasticity.

Figure 6 and the goodness of fit measures indicate the overall significance and prediction accuracy of the estimated relationship are good.

11/Various permutations of Equation (16) excluding each of the offending variables were estimated. None of these variations were as accurate in predicting historical $PSECT_t$, nor did they produce parameters having greater significance.

Table 2.--Estimated price elasticity coefficients for the wholesale section price offer relationship.

Associated explanatory variable (X_{it})	Estimated flexibility coefficients: Low $SECTSUP_t$ (1983)[a]	Mean values[b]	High $SECTSUP_t$ (1980)[c]
$SECTSUP_t$	0.0404	0.2591	0.7041
$AVEXPR_t$	0.6990	0.5602	0.4629
$QHARDP_t$	-0.0158	-0.1783	-0.5038
$INTR_t$	-0.0611	-0.1358	-0.1522
$PSECT_{t-1}$	0.2045	0.1838	0.1862

[a]The ratio of X_{it} and $\hat{PSECT}_t$ was derived from the 1983 observations. This year corresponds to the lowest recorded $SECTSUP_t$.

[b]Mean values for all variables were used to predict $PSECT_t$ and to formulate the ratio between X_{it} and $\hat{PSECT}_t$.

[c]The ratio of X_{it} to $\hat{PSECT}_t$ is based on the 1980 observations. This year corresponds to the highest $SECTSUP_t$.

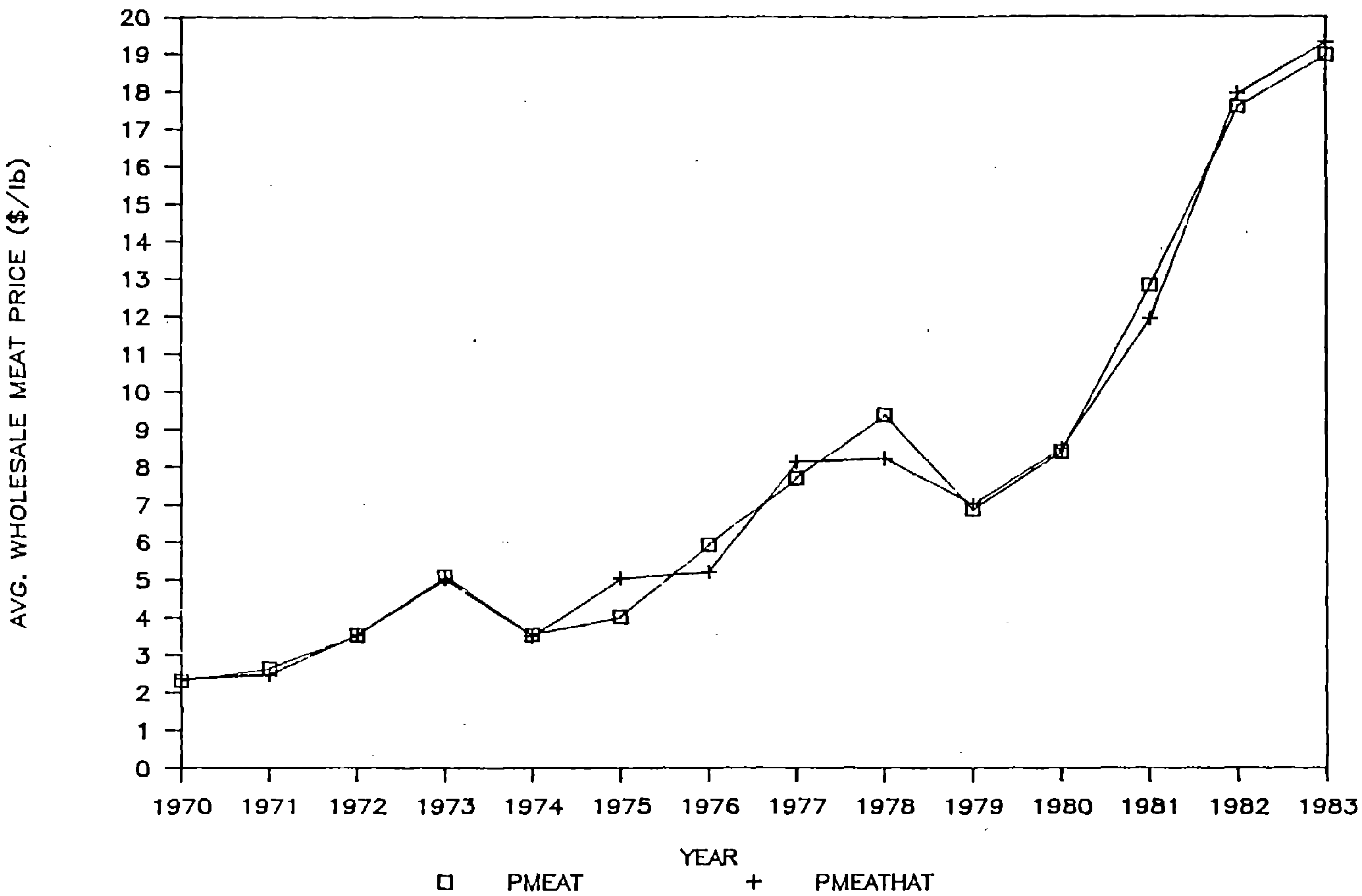

Figure 6.--Actual (PMEAT) versus predicted (PMEATHAT) seasonal average New York wholesale market price for frozen king crab meats, 1970-83.

$LAROR_t$ was retained, despite the somewhat low t-statistic, because processors report it to be an important factor in the pricing of meat products.

Ending Holdings of Frozen Sections ($SECTHOLD_t$)

Profit maximizing suppliers appear to have both transactional and speculative motives for holding frozen king crab stocks. As such, four factors conceptually influence the ending stock of frozen sections in storage: 1) current section production, 2) current price, 3) an expectation of future market price, and 4) the cost of holding stocks..

Uncertainty about crab availability and historic harvest volatility motivates price speculation behavior. For example, anticipated declines in primary supply resulting from depleted crab abundance stimulate suppliers to increase product reserves. Maintaining larger reserves not only insures that suppliers will have sufficient pipeline inventories, but also gives them an opportunity to benefit from expected increases in wholesale prices. Rising price expectations can lead to larger revenues and potential profit gains for suppliers having product in storage. The speculative motive to hold stocks, therefore, involves a comparison of current price- with expected future price.

A simple extrapolative price expectation framework is hypothesized for inclusion in the $SECTHOLD_t$ relationship. The expected future price ($PSECT^*_{t+1}$) is conceived as a a linear function of observed current and lagged market prices ($PSECT_t$ and $PSECT_{t-1}$, respectively).

$$PSECT^*_{t+1} = PSECT_t + \beta(PSECT_t - PSECT_{t-1}) \qquad (18)$$

In this case, the future price is expected to equal the current price plus some positive fraction of the difference between current and lagged prices.

The extrapolation coefficient (B) is assumed to range between zero and one. The right-hand side of Equation (18) can be used to replace $PSECT_{t+1}$ in the stock holding equation.[12/]

The third component perceived to influence $SECTHOLD_t$ is the cost of storage. Rising costs induce suppliers to decrease holdings.. The opportunity cost of maintaining section inventories appears to impart the greatest influence on stock holdings (based on discussions with industry representatives). Opportunity cost can be measured by the product of $INTR_t$ and $PSECT_t$. This product represents the dividend that could be received from selling stock holdings and investing the money at the prime rate. Rising $INTR_t$ will increase opportunity cost and motivate a reduction in stocks.

$SECTHOLD_t$ is simultaneously determined with $PSECT_t$, $PMEAT_t$, and $SECTCONS_t$. The 2SLS estimate of the holdings equation (weighted by the squared reciprocal of lagged section production to correct for heteroskedasticity) is given in Equation (19).

$$
\begin{aligned}
SECTHOLD_t = & \underset{(-5.95)}{-4.20879} + \underset{(5.89)}{0.13502}\, SECTPROD_t + \underset{(3.08)}{3.53861}\, PSECT_t \\
& - \underset{(-0.33)}{0.38722}\, PSECT_{t-1} - \underset{(-1.88)}{12.37973}\, (PSECT_t\ INTR_t) - \underset{(-3.93)}{4.25953}\, IND73 \qquad (19)
\end{aligned}
$$

$R^2 = 0.9449$ df = 8

12/In the context of empirical estimation, the parameter estimate on $PSECT_t$ is an amalgam of current period and expected price effects. The parameter on $PSECT_{t-1}$, accordingly, is not identified.

Overall accuracy and statistical significance of Equation (19) for the period from 1970 to 1983 are illustrated by the estimated goodness of fit measures and Figure 7.

An indicator variable (IND73) was included to mark a structural break in holdings that occurred in 1973. A dramatic change in the exchange rate between the U.S. dollar and Japanese yen occurred in 1973. The rate made U.S. products considerably less expensive for consumers in Japan and stimulated import demand from Japan. This, in turn, caused unusually large reductions in cold storage holdings.

$PSECT_{t-1}$ was retained in the specification despite the low t-statistic because processors repeatedly stated that future wholesale price expectations were based on both current and past prices. Prediction accuracy also was enhanced by utilizing both $PSECT_t$ and $PSECT_{t-1}$.

Stockholding elasticities are listed in Table 3. The 1983 (record low production year), 1980 (record high production year), and mean values were used to derive the three elasticities reported for each explanatory variable. Suppliers consistently are estimated to be somewhat unresponsive to changes in $SECTPROD_t$, especially at low production. This behavior would support the notion of a pipeline demand for frozen sections; a certain level of holdings will be maintained regardless of production. In contrast to production, suppliers initially are very responsive to changes in wholesale price. This elastic response probably stems from their speculative holdings motivation. Suppliers generally appear to be insensitive to changing interest rates. This finding may reflect the relative unimportance of storage costs as compared to the speculative and transaction demands for holding stocks.

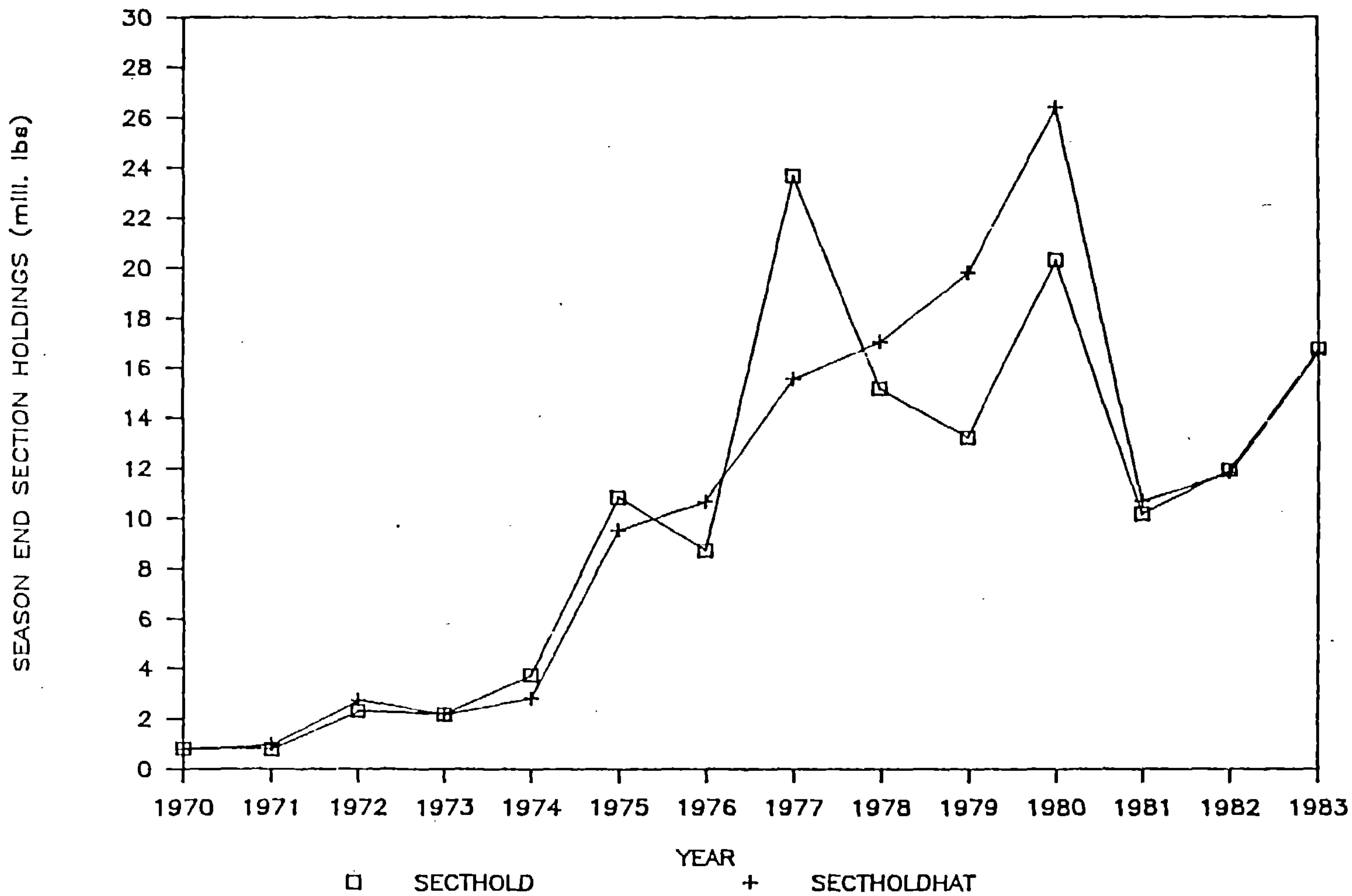

Figure 7.--Actual (SECTHOLD) versus predicted (SECTHOLDHAT) end of season frozen king crab section cold storage holdings, 1970-83.

Table 3.--Estimated elasticities for ending holdings of frozen sections.

Associated explanatory variable (X_{it})	Estimated elasticities		
	High $PSECT_t$ Low $SECTPROD_t$ (1983)	Mean values	Low $PSECT_t$ High $SECTPROD_t$ (1980)
$PSECT_t$	2.8218	3.0916	3.3242
$SECTPROD_t$	0.2160	0.7778	0.8899
$INTR_t$	-0.7168	-0.4471	-0.2144

It is important to recognize that the stockholding behavioral model presented here is inherently flawed by data deficiencies. The most serious deficiency is related to the fact that inventory data is reported on a voluntary basis. Attempts like this one to model this aspect of industry behavior are necessarily rudimentary.

Derived Supply Definitional Identities

Though both current section production ($SECTPROD_t$) and section supply ($SECTSUP_t$) could be estimated empirically, it is sufficient to specify them as endogenously determined residual identities. Both quantities are measured in million pounds on a fiscal year basis (1 July-30 June) and are estimated implicitly through the $PSECT_t$, $SECTHOLD_t$, and $SECTCONS_t$ behavioral relationships. Equating total demand with total supply and solving for domestic production yields the $SECTPROD_t$ identity.

$$SECTPROD_t = SECTCONS_t + SECTEXP_t + SECTHOLD_t - SECTHOLD_{t-1} - SECTIMP_t \quad (20)$$

Both $SECTEXP_t$ and $SECTIMP_t$ are treated as exogenous variables due to inadequate data on foreign supply and demand for king crab sections.

Domestic supplies to domestic markets ($SECTSUP_t$) equal total production plus the change in holdings during the current period.

$$SECTSUP_t = SECTPROD_t + (SECTHOLD_{t-1} - SECTHOLD_t) \quad (21)$$

The bracketed term quantifies the change in stocks.

The final identity in the derived supply framework is the weighted average of wholesale section and meat prices ($WTAVP_t$). The prices are weighted by their respective product supplies and reported on a fiscal year basis (1 July-30 June) in dollars per pound.

$$WTAVP_t = ((PSECT_t\ SECTSUP_t) + (PMEAT_t\ MEATSUP_t)) / (SECTSUP_t + MEATSUP_t) \qquad (22)$$

PRIMARY DEMAND

The U.S. demand for king crab products has grown rapidly over the past two decades. Much of this growth can be attributed to the development and introduction of frozen king crab sections in restaurants and retail stores during the early 1970s. Initial consumer acceptance for this product form was overwhelming. Expansion of the 25- to 44-year-old age group--a group considered by industry experts to be the principal consumers of king crab--contributed to the rapid growth in demand. Changing tastes and preferences along with increased per capita disposable incomes helped to sustain and further stimulate demand for the product.

Market acceptance of frozen sections combined with the high cost of meat extraction led to a precipitous decline in what had been fairly strong demand for extracted king crab meats during the 1960s. By 1977, extracted meat represented only a small fraction of total demand for king crab. Consequently, primary demand can be focused at frozen section consumption behavior, with meat consumption treated as exogenous.

Economic theory suggests five factors that can influence domestic consumption of frozen king crab sections ($SECTCONS_t$): 1) the retail section price, 2) prices of closely related consumer substitutes, 3) per capita disposable income, 4) total population, and 5) some measure of consumer tastes and preferences. Conceptually, utility maximizing consumers will use these factors to establish total primary demand for processed king crab sections. Demand for king crab should be inversely related to its own market price, but positively influenced by the prices of substitute goods. Increasing incomes, population, and tastes and preferences all should motivate growth in demand. Unfortunately, data for several of these factors either are nonexistent or extremely difficult to quantify.

A consistent time series of retail section prices are not available for the study period. Wholesale prices ($PSECT_t$), however, are available and presumably have been a relatively constant proportion of retail prices.

Lobster appears to be the principal substitute for king crab legs (sections) in the minds of most consumers. A consistent price series on American lobsters is available only in the form of an ex-vessel price index ($PLOB_t$), reported by the National Marine Fisheries Service (Current Fisheries Statistics, various years). As with crab prices, it is assumed that the American lobster ex-vessel price index is linearly correlated with domestic retail prices.

The primary demand Equation (23) was estimated using 2SLS because $SECTCONS_t$ is simultaneously determined with $PSECT_t$ and $SECTHOLD_t$. This specification was estimated twice, once using nominal monetary values, assuming the presence of money illusion, and once with real values. The nominal results were found to be superior based on goodness of fit statistics and prediction accuracy.

$$SECTCONS_t = \underset{(-4.687)}{-61.76014} - \underset{(-6.536)}{21.87475}\, PSECT_t + \underset{(2.143)}{36.40434}\, PLOB_t$$

$$+ \underset{(2.477)}{0.01675}\, INC_t - \underset{(-1.617)}{18.77098}\, IND74 \qquad (23)$$

$R^2 = 0.9031$ $\quad$ df = 10

Estimated goodness of fit measures and Figure 8 illustrate the overall accuracy and significance of Equation (23) for the period from 1970 to 1983.

An indicator variable marking 1974 (IND74) was included to account for a one-period structural break in consumer behavior. The average wholesale price of sections ($PSECT_t$) decreased 32% between 1973 and 1974, from $2.716 per pound to $1.843 per pound. Processors faced with a 25% rise in total harvest, reduced their wholesale offer prices for both sections and meats, thereby creating an incentive for consumers to increase the quantity of sections demanded. No such increase was observed, perhaps due to insufficient market information, weak demand, or inadequate domestic market supplies.

Attempts to incorporate population as an explanatory variable resulted in insignificant parameter estimates and poorer predictions. Two population variables were tested: total U.S. population and the 25- to 44-year-old age group.

Demand elasticities were calculated with respect to each explanatory variable to determine consumer- responsiveness to changing conditions. The elasticity estimates listed in Table 4 are normalized on high, mean, and low $PSECT_t$ levels. In all cases, consumers appear to be very sensitive to changing conditions. The generally elastic response conforms to expectations for a luxury good like this shellfish commodity. Only during the periods of very high consumption and extremely low price will consumers be slightly unresponsive to price changes; consumer welfare is greater under larger stock/supply conditions.

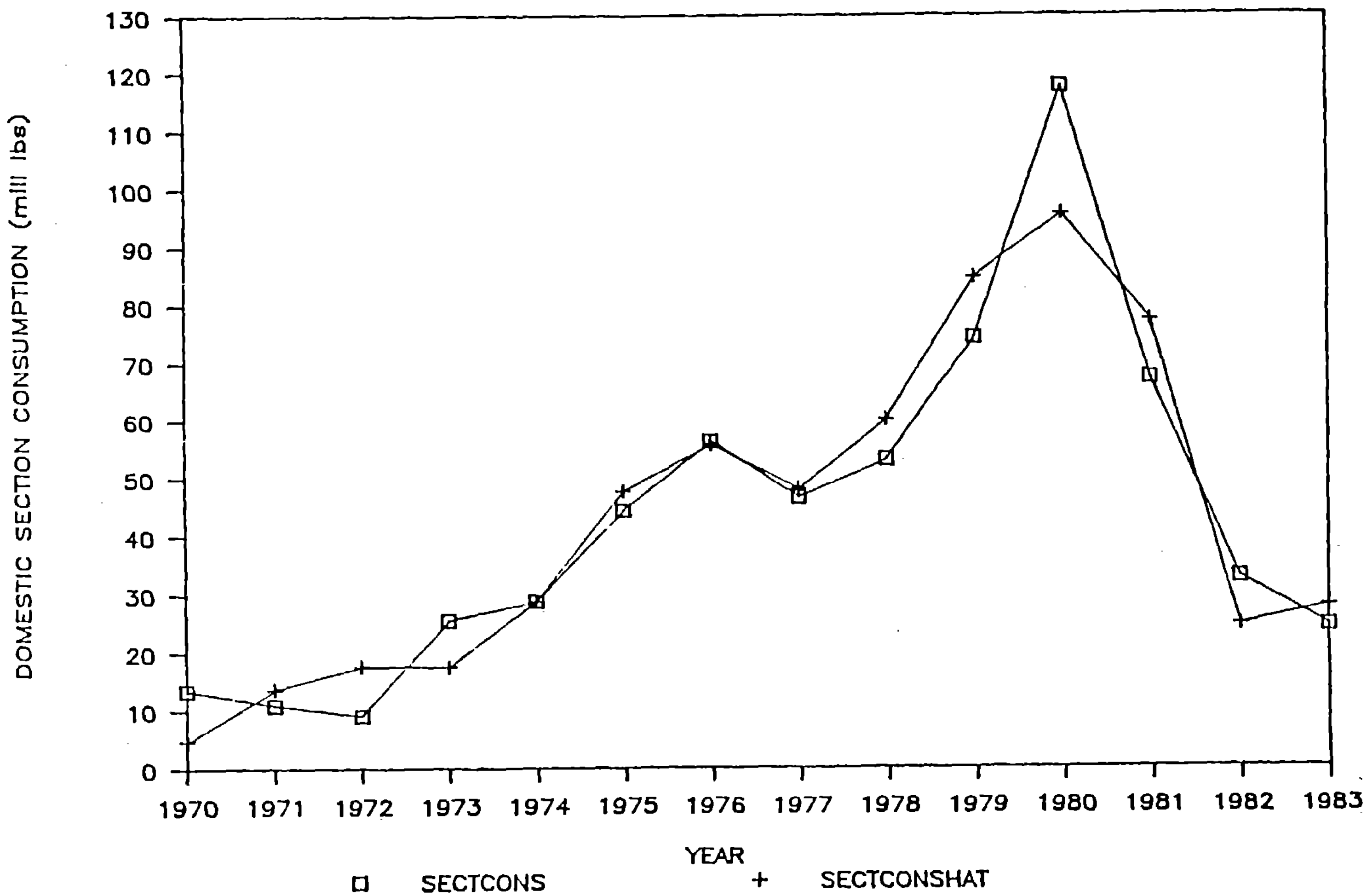

Figure 8.--Actual (SECTCONS) versus predicted (SECTCONSHAT) domestic consumption of frozen king crab sections for the period 1 July-30 June, 1970-83.

Table 4.--Estimated demand elasticities.

Associated explanatory variable (X_{it})	Estimated elasticities		
	Low $PSECT_t$ (1980)[a]	Mean values[b]	High $PSECT_t$ (1983)[c]
$PSECT_t$	-0.9107	-1.9367	-7.2179
$PLOB_t$	1.1392	1.9753	4.3790
INC_t	1.4176	2.4233	6.0595

[a] The ratio of X_{it} and $\hat{SECTCONS}_t$ was derived from the 1980 observations. This corresponds to the lowest recorded wholesale price for king crab sections observed since sections became the principal product form.

[b] Mean values for all variables were used to predict $SECTCONS_t$ and formulate the ratio between X_{it} and $\hat{SECTCONS}_t$.

[c] The ratio between X_{it} and $\hat{SECTCONS}_t$ is based on the 1983 observations. This year produced the highest recorded $PSECT_t$ during the study period.

SUMMARY OF THE MARKET MODEL

In summary, the market model traces the movement of raw crab from the point of harvest to wholesale market distribution. It can be represented by two segmentable components: the harvest sector and the processed product sector. Structural features of the harvest and processed product sectors can be illustrated in matrix form by Tables 5 and 6, respectively. These two sectors are linked through the lagged weighted average wholesale price variable ($WTAVP_{t-1}$). Market clearing is assured by the residual harvest identity specification for $QHARVW_t$.

Additional research is needed to incorporate the Japanese demand for king crab, which has had an important impact on the U.S. market. Unfortunately, this initial attempt at modeling the market for Alaska king crab was not able to incorporate factors that contribute to the export market. A second weakness in this study that warrants further research concerns capital stock formation--investment and disinvestment in the fleet. The vessels equation is rudimentary. Stockholding behavior equations are also in need of additional research. Of course, the most problematic aspect of this study centers on the need to treat all harvest areas other than the Bristol Bay (area T) as residual claimants. The lack of trawl survey data that connects the primary supply of king crab stocks to this market model is not likely to be resolved in the foreseeable future.

Table 5.--Summary of harvest sector market submodel.

Dependent variable	QHARVT	QHARVW	LEGALS	NONLEGALS	POTLIFTS	EXPRT	GUIDE	VESSELS	DAYS	WPUE	WTAVP	INTR	FUEL	EXPRW	SECTPROD	MEATPROD	QHARVUS	QHTDAY	QHWDAY	PLANTS
	Explanatory variables																			
QHARVT			X	X	X															
POTLIFTS			L			X	X	X	X											
VESSELS	L		L			L		L												
EXPRT	X									X	L	X	X							
WPUE	X				X															
AVEXPR	X	X				X								X						
QHARVW	X														X	X				
QHARVUS	X	X																		
QHTDAY	X								X											
QHARDP																	X	X	X	X

X denotes current value of explanatory variable.

L denotes lagged value of explanatory variable.

Indicator variables are not included in this summary.

Table 6.--Summary of processed product sector market submodel.

Dependent variable	SECTSUP	AVEXPR	QHARDP	PSECT	INTR	LABOR	PLOB	INC	SECTPROD	SECTCONS	SECTHOLD	SECTEXP	SECTIMP	PMEAT	MEATSUP
	Explanatory variables														
PSECT	X	X	X	L	X										
PMEAT				X		X									
SECTCONS				X			X	X							
SECTHOLD				XL	X				X						
SECTPROD										X	XL	X	X		
SECTSUP									X		XL				
WTAVP	X			X										X	X

X denotes current value of explanatory variable.

L denotes lagged value of explanatory variable.

Indicator variables are not included in this summary.

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Appendix 1.--Variable definitions.

Variable Name	Definition	Data source
Harvest Sector of Market Submodel		
QHARVT	Total seasonal domestic southeastern Bering Sea (Bristol Bay) king crab harvest (million pounds) for the ADF&G regulation year 1 July-30 June.	2
POTLIFTS	Total seasonal potlifts made by fishermen harvesting king crab in the southeastern Bering Sea (Bristol Bay) reported on an ADF&G regulation year basis (1 July-30 June) in million potlifts.	2
VESSELS	Total seasonal fleet size harvesting king crab in the southeastern Bering Sea (Bristol Bay) reported on an ADF&G regulation year basis (1 July-30 June).	2
EXPRT	Seasonal average ex-vessel price ($/pound) paid to fishermen harvesting king crab in the southeastern Bering Sea (Bristol Bay) for the ADF&G regulation year 1 July-30 June.	2
WPUE	Seasonal average legal biomass of king crab harvested per potlift (i.e., weight per unit effort) in the southeastern Bering Sea (Bristol Bay) during the ADF&G regulation year 1 July-30 June. Derived as the quotient of QHARVT and POTLIFTS.	14
AVEXPR	Seasonal weighted average ex-vessel price ($/pound) paid to fishermen harvesting king crab in all registration areas for the ADF&G regulation year 1 July-30 June. Derived as the average of EXPRT and EXPRW (an exogenous variable) weighted by their respective seasonal harvests: QHARVT and QHARVW.	14
LEGALS	Biomass (million pounds) of legally harvestable male king crab as determined by minimum size limit in the southeastern Bering Sea for the ADF&G regulation year 1 July-30 June. Derived from the sum of all MALE914 crab and that portion of MALE8 crab that are legally harvestable.	2, 14
NONLEGALS	Biomass (million pounds) of all adult king crab that <u>are not</u> legally harvestable in the southeastern Bering Sea during the ADF&G regulation year 1 July-30 June. NONLEGALS is derived as the difference between all adult king crab (i.e., MALES14 + FEM514) and the legally harvestable biomass (LEGALS).	14

Variable name	Definition	Data source
QHARVW	Total seasonal domestic king crab harvest (million pounds) from all areas outside the southeastern Bering Sea for the ADF&G regulation year 1 July-30 June.	2
QHARWS	Total seasonal domestic king crab harvest (million pounds) from all U.S. waters for the ADF&G regulation year 1 July-30 June.	2
QHTDAY	Seasonal average king crab biomass harvested domestically per day from the southeastern Bering Sea (Bristol Bay) for the ADF&G regulation year 1 July-30 June. QHTDAY is derived as the quotient of QHARVT and season length in the southeastern Bering Sea (DAYS). The quotient is multiplied by 1,000 to calibrate QHTDAY in 1,000 pounds per day.	14
QHARDP	Seasonal average king crab biomass caught domestically per day per-plant for all Alaskan harvest areas for the ADF&G regulation year 1 July-30 June. QHARDP is derived as the average of QHTDAY and QHWDAY (an exogenous variable) weighted by QHARVT and QHARVW respectively then divided by the exogenously determined total number of king crab processing plants operating in Alaska (PLANTS). This variable is reported in 1,000 pounds per day per plant.	14

Processed Product Sector. of Market Submodel

Variable name	Definition	Data source
PSECT	Seasonal average New York wholesale market price ($/pound) for frozen king, crab sections corresponding to the ADF&G regulation year 1 July-30 June. PSECT is. the simple average of reported monthly prices.	7
PMEAT	Seasonal average New York wholesale market price (S/pound) for frozen king crab meats corresponding to the ADF&G regulation year 1 July-30 June. PMEAT is the simple average of reported monthly prices.	7
SECTCONS	Total seasonal U.S. domestic consumption of frozen king crab sections for the ADF&G regulation year 1 July-30 June. SECTCONS is calculated as the sum of domestic section production (SECTPROD) and imports (SECTIMP) less section exports (SECTEXP) and change in stock holdings ($SECTHOLD_{t-1}$ - $SECTHOLD_t$). All quantities are reported on a live weight equivalent basis (1 pound of processed sections = 1.67 pounds of raw king crab) in million pounds.	14

Variable name	Definition	Data source
SECTHOLD	Total domestic season ending cold storage holdings of frozen king crab sections for the ADF&G regulation year 1 July-30 June. SECTHOLD is derived from monthly holdings data and reported on a live weight equivalent basis (1 pound of processed sections = 1.67 pounds of raw king crab) in million pounds.	7
SECTPROD	Total seasonal U.S. production of frozen king crab sections for the ADF&G regulation year 1 July-30 June. Annual processed king crab production data provided by the ADF&G is used to determine what percentage of all production (on a live weight equivalent basis) is in the section form. This percentage is then multiplied by total domestic seasonal harvest (QHARWS) to estimate seasonal section production. SECTPROD is reported on a live weight basis in million pounds.	3
SECTSUP	Total seasonal domestic supply of frozen king crab sections to U.S. wholesale markets for the ADF&G regulation year 1 July-30 June. SECTSUP is derived as the sum of domestic section production (SECTPROD) plus the change in stock holdings ($SECTHOLD_{t-1}$ - SECTHOLD) on a live weight equivalent basis in million pounds.	14
WTAVP	Weighted average seasonal New York wholesale market price ($/pound) for both frozen king crab sections and meats corresponding to the ADF&G regulation year 1 July-30 June. WTAVP is the average of section (PSECT) and meat (PMEAT) seasonal wholesale prices weighted by domestic section (SECTSUP) and meat (MEATSUP) supplies to U.S. wholesale markets.	14
<u>Exogenous Variables</u>:		
GUIDE	Seasonal king crab harvest guideline (million pounds) for the southeastern Bering Sea (Bristol Bay) ADF&G management area.	2
DAYS	Total season length (in days) for the southeastern Bering Sea (Bristol Bay) king crab harvest.	2
INTR	Third quarter prime interest rate charged by banks as reported by the U.S. Federal Reserve.	11
FUEL	Seasonal average diesel fuel price ($/gallon) paid by farmers in Washington for the ADF&G regulation period 1 July-30 June. FUEL was derived as a simple average of reported monthly average prices.	9

Variable name	Definition	Data source
LABOR	Annual average wage rate paid to food and kindred products workers in Alaska ($/hour).	8
PLOB	Annual U.S. ex-vessel price index for American lobster (1967 = 1.00).	6
INC	Annual U.S. per capita, disposable income (nomimal $/person).	10
EXPRW	Seasonal average ex-vessel price (S/pound) paid to fishermen harvesting king crab in areas other than the southeastern Bering Sea (Bristol Bay) for the ADF&G regulation year 1 July-30 June. EXPRW is derived as an average of ex-vessel prices from the other harvest areas weighted by total catch.	10
MEATPROD	Total seasonal U.S. production of frozen and canned king crab meats for the ADF&G regulation year 1 July-30 June. Annual processed king crab data provided by ADF&G is used to determine what percentage of all production (on a live weight equivalent basis) is in the meat form. This percentage is then multiplied by total domestic seasonal harvest (QHARWS) to estimate seasonal meat production. MEATPROD is reported on a live weight equivalent basis (1 pound of processed meats = 4 pounds of raw king crab) in million pounds.	14
MEATSUP	Total seasonal domestic supply of frozen and canned king crab meats to U.S. wholesale markets *for* the ADF&G regulation year 1 July-30 June. MEATSUP is derived as the sum of domestic meat production (MEATPROD) plus the change in meat stock holdings ($MEATHOLD_{t-1}$ - MEATHOLD) on a live weight equivalent basis in million pounds.	14
NEATHOLD	Total domestic season ending holdings of frozen and canned king crab meats for the ADF&G regulation year 1 July-30 June. MEATHOLD is derived from monthly holdings data and reported on a live weight equivalent basis in million pounds.	7
QHWDAY	Seasonal average king crab biomass harvested domestically per day outside the southeastern Bering Sea (Bristol Bay) management area for the ADF&G regulation year 1 July-30 June. QHWDAY is derived as the weighted average of quantity harvested per day in each of the non-Bristol Bay management areas. The average is reported in thousand pounds per day.	2

Variable name	Definition	Data source
PLANTS	Annual number of plants processing raw king crab in Alaska.	1
SECTEXP	Total seasonal U.S. export of frozen king crab sections for the ADF&G regulation year 1 July-30 June. SECTEXP, is reported-on a live weight basis, millions of pounds.	12
SECTIMP	Total seasonal U.S. import of frozen king crab sections from the Soviet Union, for the ADF&G regulation year 1 July-30 June. SECTIMP is reported on a live weight basis', millions of pounds.	13

[1]Data sources are as follows:

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