HEDONIC PRICES FOR FISH: TUNA PRICES IN HAWAII

KENNETH E. MCCONNELL AND IVAR E. STRAND

Over the past two decades, the marketing of fish has recognized the importance of quality. Yet empirical analysis of market transactions could give us little insight into the value of different qualities of fish because market data are typically aggregated. We exploit a dataset on the auction price of tuna sold in Hawaii to estimate a hedonic model. The model provides empirical estimates of price increments due to species, quality of the fish such as size or fat content, method of handling, and market conditions. The empirical results are also used to estimate price flexibilities for landings in Hawaii.

Key words: fish prices, fish quality, hedonic models, tuna.

Recent analyses of fisheries markets have begun to devote more attention to the quality attributes of fish. This is partly attributed to better availability of data; however, the increased concern for managing fisheries (Blomo et al., Wang and Kellogg) and the expansion of controlled production through aquaculture (Anderson and Kusakabe) may also be factors. Harvesters and fishery managers have an interest in learning about the costs and prices of fish characteristics. Conjoint analysis is the most prevalent approach of learning about consumer preferences for fish. This method relies on answers to hypothetical responses to survey questions from market participants regarding their preferences for seafood with differing characteristics (Anderson and Brooks; Anderson and Kusakabe; Wirth, Halbrandt, and Vaughan; Silvia and Larkin). The information that market transactions reveal about preferences for fish characteristics has not been exploited. In this paper we estimate hedonic price functions for tuna, hence uncovering behavioral information about the marginal values of fish characteristics.

In Hawaii fisheries, most tuna are sold in two auctions, the United Fishing Auction in Honolulu and the Suisan Auction in Hilo. The Hawaii markets offer a rare opportunity to study revealed preferences for quality attributes of fish.[1] The transactions in these markets induce trade-offs between price and attributes of fish. Hence they are revealed, not stated, preferences. Because the Japanese sashimi market for tuna is so discerning of quality, most harvested tuna in Hawaii are auctioned individually, with their prices reflecting a willingness to pay for the quality attributes of the individual fish. Figure 1 shows the systematic variation in the price of fish of different grades. Buyers act as middlemen to purchase tuna for resale in the local Hawaiian market, Japanese market, and the mainland U.S. markets. They bid for tuna based on their knowledge of the willingness to pay for the fish in subsequent markets, given its attributes.

The prices that emerge in the auctioning of fish can be considered hedonic prices. The price of an individual fish depends on its characteristics, including species, fat content, type of handling, and fish size. Hedonic fish prices are similar in concept to hedonic housing prices, which depend on characteristics such as location, square feet of floor space, lot size,

The authors are professors in the Department of Agricultural and Resource Economics at the University of Maryland.

The authors thank Paul Bartram, Rita Curtis, Marcia Hamilton, Johan Mistiaen, Sam Pooley, John Sibert, Mike Travis, two anonymous reviewers, and the editor for comments. The authors appreciate support from the Joint Institute for Marine and Atmospheric Research at the University of Hawaii. The authors are especially grateful to Paul Bartram, Peter Garrod, and John Kaneko for giving us access to the dataset.

[1] The Pacific Fisheries Research Program recognized the importance of quality and price of tuna by commissioning the study "Quality and Product Determination as Price Determinants in the Marketing of Fresh Pacific Tuna and Marlin" (Bartram, Garrod, and Kaneko). The Bartram and colleagues study provides excellent descriptions of tuna product types and major markets. On the basis of average prices categorized by attributes, quality differentiated market attributes were judged to be present. We are grateful to them for giving us access to this dataset.

Amer. J. Agr. Econ. 82 (February 2000): 133–144
Copyright 2000 American Agricultural Economics Association

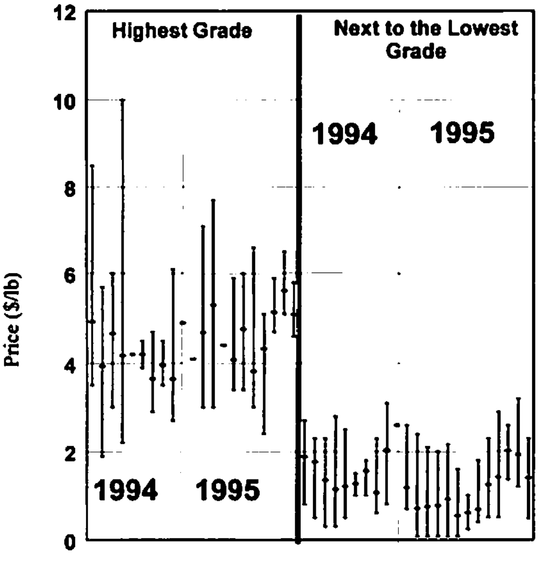

Figure 1. Average daily Hawaiian yellowfin tuna prices for highest and next to the lowest grade; average (_), high and low (-)

and so on. The earliest study of hedonic prices for food, and what must also be the earliest empirical hedonic study of any study, was carried out by Waugh in 1927, who studied how quality determined the price of vegetables (Waugh 1928). Today there is a considerable literature on the hedonic prices of agricultural commodities, including tomatoes (Bierlen and Grunewald), apples (Tronstad et al.), wheat (Espinosa and Goodwin), cotton (Brown et al.), milk (Gillmeister et al.), beef (Brester et al.), and grapes (Golan and Shalit). However, the hedonic study of fish prices appears underdeveloped, despite the growing awareness that the quality of fish is an important characteristic of seafood markets.

While the estimation of hedonic prices for fish is inherently interesting, the results will illustrate the continued evolution of the role of quality in fisheries markets. This development has had a significant effect in the marketing of salmon, where the consistent quality of cultured fish has been influential in increasing the share of such fish in salmon markets. Quality may ultimately play a role in the management of tuna. Fisheries policy, designed in part to harvest fish in a socially efficient way, will be called upon to recognize that some forms of harvest provide more value added than other forms, because they create better products at the market. We provide some evidence of this phenomenon in the analysis of hedonic prices of tuna. Prices for fish landed by some types of gear are higher than for other types of gear, presumably because consumers value fish from some gear types more than others. The gear preference reflects some unresolved uncertainty about fish quality, rather than an innate preference for production process.

In the present analysis of the hedonic tuna prices, we address three issues. The first pertains to the empirical content of the hedonic prices. We provide evidence that fish characteristics induce systematic variation in the price of fish. For example, bigeye command $.93 per pound more than albacore. The second issue concerns the grading of fish. Buyers provide an introspective or "mental" grade when they examine a fish to determine its quality. How much information do these grades contain? Can the price of fish be explained exclusively by the grade of the fish, or do the characteristics of the fish provide additional information? Hedonic models show that for a given species, knowing the grade of the fish is almost as good as knowing all the technical characteristics of fish in predicting the price. Finally, we try to understand the degree to which the auction prices are determined by quantities landed on the day the fish is sold. The question relates to Hawaii commercial fishing enterprises and landings. Do additional landings depress price and if so, by how much? We find that for yellowfin and bigeye, species that are likely to be consumed in Hawaii as well as exported, additional landings are likely to depress price.

The auctions in Hawaii are English auctions. The bidding is oral and the fish goes to the highest bidder. The buyers at the auction sell their products in three markets: the Japanese market, local consumption in Hawaii (i.e., grocery stores and restaurants), and the U.S. mainland market for tuna. The buyers typically review and grade the fish separately prior to the auction. The buyers presumably have good knowledge of the fish and the markets they sell in but not the values held by other buyers. They have all operated in the market in the past, however, and so they can be assumed to know the probability distribution of the each other. Hence, it is reasonable to think of this auction as one where the independent-private-values assumption applies (see McAfee and McMillan, p. 706). The equilibrium price is the value of the second highest bidder. In the English auction, each buyer bids independent of the valuation others place on the good. While other auctions might work for the sale of fish, the English auction yields the same expected price as the other most common auctions such as the Dutch auction or the second price auction.

The auctions begin early each day. The fish are laid out on pallets, identified by vessel. Larger fish have small plugs of flesh taken so that buyers can determine flesh characteristics. Buyers typically represent large dealers and local markets. The auctioneer proceeds through the fish, with the buyers following and bidding on each tuna orally. When less desirable species than tuna are auctioned, they sometimes are sold as lots, rather than individual fish. Of the two auctions, United Fishing Auction in Honolulu is much the larger. The Suisan Auction in Hilo is quite informal, taking on the appearances of a tourist attraction because it can be observed from the sidewalk.

A Hedonic Price Equation and the Marginal Value of Characteristics of Tuna

In the hedonic model, the increment in price due to increases in any characteristic will equal the buyers' marginal willingness to pay for the characteristic, as well as the marginal cost of producing the characteristic for sellers. When buyers and sellers have time to adjust their responses, the marginal hedonic price equals the marginal value to consumers and the marginal cost to suppliers. In the very short run, such as prevails in fish auctions, equality between the marginal hedonic price and marginal willingness of buyers to pay holds. However, equality between prices and the marginal cost of production would require a longer horizon.

The data for the study come from a survey by Bartram, Garrod, and Kaneko. They collected data from the Hawaii tuna and marlin auction, recording individual fish prices and the quality or characteristics of the fish. These data were collected on twenty-three days at the end of June and beginning of July in both 1994 and 1995.[2] The days are not consecutive in either year. Table 1 shows the days on which fish prices were collected, the mean price and the number of fish. Based on their

Table 1. Mean Prices of Tuna and Number of Fish, by Day

Month/Day	Mean Price ($)	Number of Fish
1994		
6/30	2.36	320
7/1	2.50	392
7/6*	1.77	357
7/7	1.98	371
7/8	1.80	186
7/9	2.11	191
7/11*	2.43	231
7/12	2.00	305
7/13	2.48	108
7/14	3.21	56
1995		
6/23	1.77	151
6/24	1.59	258
6/26*	1.38	459
6/27	1.69	350
6/28	1.25	661
6/29	1.21	623
6/30	1.17	242
7/1	1.25	370
7/3*	1.11	680
7/5*	1.24	772
7/6	1.50	427
7/7	1.64	474
7/8	1.31	651

* The days with asterisks are not consecutive.

experience as seafood buyers (Bartram and Kaneko are buyers in the Honolulu market), Bartram and colleagues also provided their assessment of the "grade" of each tuna. The grading melds the individual attributes of each tuna into a numeric scale for six categories. Table 2 gives the relevant characteristics and their means for the tuna in the dataset.

To express the hedonic price analytically, let P_{it} represent the price of the ith fish on the tth day of the survey and let $\mathbf{Z_i} = (Z_{i1}, Z_{i2}, \cdots Z_{iJ})$ be the J characteristics that determine the price of the fish. Then the hedonic price equation can be written

$$(1) \quad P_{it} = F(\mathbf{Z_i}, t)$$

where F is the function that relates price P_{it} to the individual Z_{ij}. This is not a time-series in the traditional sense, because the days are not consecutive and observations are only available for one day. Hence we suppress the argument t. The only significant variable to change across the days is the landings. The marginal price of the jth characteristic, say Z_{ij}, is given by the partial derivative:

[2] The results depend on the sampling period, late June and early July 1994 and 1995. This season has especially heavy landings of longline-caught fish. Furthermore, during this time demand is relatively low. Despite these shortcomings, we believe that the results help in understanding the marketing of tuna in Hawaii and in demonstrating how important quality factors are.

Table 2. Characteristics of Tuna Sold in the Hawaii Fish Auctions

Variable	Description	Mean	Standard Deviation
P_{SELL}	Price per pound of fish	1.58	1.21
D_{YF}	1 if yellowfin	0.35	0.48
D_{BE}	1 if bigeye	0.24	0.43
D_{AL}	1 if albacore	0.41	0.49
D_{LL}	1 if landed on longliner	0.83	0.39
D_{HND}	1 if landed on handliner	0.12	0.32
D_{TRL}	1 if landed on troller	0.05	0.22
D_{WHL}	1 if fish is whole	0.76	0.42
D_{HGUT}	1 if fish is headed and gutted	0.07	0.26
D_{GILLED}	1 if fish is gutted and gilled, loined, or other	0.17	0.38
W_{whl}	Whole weight of fish, in pounds	87.7	48.4
$\sum W_{BE}$	Weight of bigeye landings for the day (in 10,000 pounds)	0.927	0.622
$\sum W_{AL}$	Weight of albacore landings for the day (in 10,000 pounds)	1.213	0.809
$\sum W_{YF}$	Weight of yellowfin landings for the day (in 10,000 pounds)	1.75	0.652
$BURN_0$	1 if the fish is labeled not burned (1994 only)	0.27	0.44
$BURN_1$	1 if the fish is labeled slight burn (1994 only)	0.72	0.27
$BURN_2$	1 if the burn label is more severe (1994 only)	0.005	0.073
$BURN_3$	1 if the burn is most severe (1994 only)	0.004	0.065
D_{NFAT}	1 if the fish is labeled no fat (1994 only)	0.804	0.396
D_{SFAT}	1 if the fish is neither labeled fat nor not fat (1994 only)	0.178	0.382
D_{FAT}	1 if the fish is labeled fat (1994 only)	0.018	0.13

Note: There are 8,635 complete observations for tuna in the dataset.

$$(2)\quad \partial P_i/\partial Z_{ij} = \partial F(\mathbf{Z}_i)/\partial Z_{ij}.$$

The characteristics vary across days, and hence so do the marginal prices of fish. In equilibrium the slope equals the marginal value to the consumer.

The estimation of the hedonic price function is the subject of a vast literature. We concentrate on the issues relating to marginal values by estimating a linear function. A simple linear form makes the results on marginal prices transparent. Also, the characteristics of fish tend to be measured quite well compared with other hedonic markets, and the very large number of observations reduces the influence of errors in measurement compared with the analysis of Cropper and colleagues. We choose the linear form

$$(3)\quad P_i = \boldsymbol{\beta}\mathbf{Z}_i + \varepsilon_i$$

where $\boldsymbol{\beta}$ is the vector of J coefficients to be estimated, and ε_i is a random error.

To illustrate the effect of characteristics on hedonic prices, we choose from the set of characteristics in table 2. Of the 8,635 tuna in the analysis, 35% are yellowfin, 24% are bigeye, and 41% are albacore. Omitted from the analysis were 175 skipjack because they are typically not auctioned as individual fish but are sold in lots. Furthermore, the number of skipjack seemed too few to exploit in a dataset that included over 8,000 fish. The data gathered were not the same for both years. The variables describing whether the fish was burned as well as the degree of fat were only available for 1994. We explain below the treatment of variables that are only available in 1994. (See the discussion of equation (4).)

The estimated model includes all the variables in table 2 except the default variables $BURN_1$, D_{SFAT}, D_{TRL}, and D_{GILLED}. The constant term in the regression includes the joint effects of the categories not included. Consequently, the variables indicating the method of landing, species, method of handing, or characteristics of the flesh should be interpreted as the increase or decrease over the default case.

Table 3 provides the coefficients for the ordinary least-squares model of the hedonic price function. This model of 8,635 observations on tuna prices explains 44% of the variation in prices, as given by the $\bar{R}^2$. The t-statistics on the estimated coefficients tend to be quite large. Twelve of the seventeen variables in the model are significant at the 1% level, implying a high level of confidence about most of the coefficients. Other functional forms explain similar proportions of the variation in price, and give similar quali-

Table 3. Linear Hedonic Model of Tuna Prices

	Coefficient	*t*-statistic
CONSTANT	-60.88	0.235
YEAR	0.030	0.235
D_{YF}	0.919	28.65
D_{BE}	0.931	33.47
$BURN_0$	0.248	1.990
$BURN_2$	-0.440	-2.462
$BURN_3$	-0.941	-4.873
W_{whl}	0.008	29.343
D_{HGUT}	1.007	21.173
D_{WHL}	1.247	37.894
D_{LL}	-0.241	-4.943
D_{HND}	-0.093	-1.738
D_{NFAT}	-0.335	-7.485
D_{FAT}	1.001	12.973
ΣW_{YF}	-0.075	-3.911
ΣW_{BE}	-0.177	-9.309
ΣW_{AL}	0.008	0.468
Observations	8,635	—
$\bar{R}^2$	0.446	—

tative results on the significance of the marginal prices, but induce variations in the marginal prices. The potential range of functional forms is limited because so many of the covariates are categorical, precluding most of the transformations that occur in Box-Cox models. Because the error structure is rather peculiar, given the nature of the data, typical tests on residuals are not meaningful. Instead of performing these tests, we plot the average residual for each day of our analysis (figure 2). These residuals are the mean residuals for the day; that is, the residual of each fish price averaged across all the fish sold for the day. Note that the days given on the horizontal axis are not consecutive. (The specific days are listed in table 1.) If the days were consecutive, and the residuals showed a clear pattern, then one might wonder about the time series structure, or omitted variables. However, there is no pattern to the residuals.

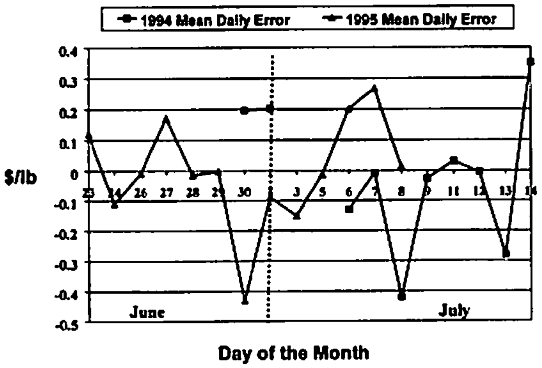

Figure 2. Mean price residuals, by day, 1994 and 1995

The set of variables indicating the degree of burn and fat on a fish are available only for 1994, as noted. We have estimated the model so that the coefficients on these characteristics are conditional on the characteristics being available. To demonstrate that the specification below isolates the effects of missing variables (from the 1995 observations) from the effects of the characteristics themselves, consider only the fat variables: D_{NFAT}, D_{SFAT}, and D_{FAT}. These variables are available for 1994 only. Consider the concentrated model

$$P = \beta_0 + \beta_1 D_{NA} + \beta_2(1 - D_{NA})D_{NFAT} + \beta_3(1 - D_{NA})D_{FAT} + \text{error}$$

where D_{NA} takes the value of one for observations when there are no data on the fat characteristics (in 1995). Hence, the coefficient β_1 represents the effect of not observing the characteristics. D_{SFAT} is the default characteristic. Although there are seven characteristics (four burn and three fat), there can be only one variable representing missing characteristics because all seven characteristics are missing for each 1995 observation. This model is equivalent to the estimated model; instead of a dummy for data not available, the actual value of year was included. This serves only to shift the constant term because D_{NA} = YEAR − 1994.

In the estimated model, we treat fish as a generic good. That is, all species are pooled in the same model, and the effect of the characteristics, such as species or grade, are estimated. Another approach would be to estimate hedonic models for particular kinds of fish, such as yellowfin, bigeye, and albacore. Such a model would give somewhat different results, simply because it represents a slight variation in functional form.[3]

The coefficients represent the direct effect of the characteristics on the price of the fish; that is, the marginal value of characteristics. Most of the variables are categorical, explaining whether the fish being sold is in a particular category. The hedonic price coefficient of

[3] Another potential model would be to estimate hedonic models for each grade. In a longer report, we compare models of market demand that are aggregated by grade with models that are aggregated by species, finding that the aggregation by grade gives more plausible results. (See McConnell, Strand, and Curtis for details.)

a categorical characteristic is the price difference over the default case of the category not included. To illustrate, the coefficient on D_{YF} represents the increase in price per pound paid for yellowfin over albacore, which in this case is estimated to be \$.919 per pound.

The coefficient on D_{BE} has the analogous interpretation; that is, bigeye on average sells for \$.931 per pound more than albacore. The "BURN" variables represent the influence of burns on the price of a fish. Flesh becomes burned for a variety of reasons: poor handling of harvested fish, excessive struggle on longlines, and warm water. The tuna in this auction were harvested during the summer, when water temperature is high. Hence, there is likely to be a higher preponderance of burned fish. The default burn level is $BURN_1$, which means that there is some burn of the muscle of the fish. (The best fish have no burn.) The higher the BURN variable, the greater the burn. This is reflected in the prices, which show that the premium for no burn over some burn is \$.248 per pound ($BURN_0$), while the discount for burn more serious than some burn is \$.44 to \$.94 per pound, depending on the severity of the burn. The variable W_{whl} is the weight of the whole fish. There is a premium for larger fish. The coefficient on W_{whl} measures this size premium. On average across all species, the price per pound increases by \$.008 (almost a cent a pound) for each pound increase in the weight of the fish. Thus, not only do bigger fish give more pounds, but also the price per pound goes up.

The fat content of the fish shows up in the coefficients D_{NFAT} and D_{FAT}. The default case is some fat, and the coefficients show the increment in price per pound over the "some fat" category. When there is no fat, the price falls by \$.335 per pound, and when the fat content is high, the fish gets a premium of \$1.00. High fat content is one trait of fish bound for the sashimi market.

The method of handling the fish (i.e., how the fish is treated after harvest), influences how the fish can be used and hence to what market it will be sent. The default handling method is gilled and gutted, loined, and some other methods for handling fish. The D_{HGUT} coefficient implies that the price per pound for headed and gutted fish is \$1.007 higher than the default case. The premium per pound for whole fish comes from the coefficient on D_{WHL}, which is more than a dollar—\$1.247. The powerful influence of having a fish that is whole reflects greater certainty about the condition of the fish. Often fish are headed and gutted or loined when there is some belief that their flesh is in some way inferior, perhaps burned or damaged in some way. Heading and gutting a fish reduce the handling costs.

Table 4. Mean Price and Weight of Yellowfin, by Gear Type

Gear Type	Mean Price	Mean Weight
Longlining	\$2.11	123.7
	(0.031)[a]	(1.29)
Trolling	2.04	106.8
	(0.035)	(7.78)
Handlining	2.55	133.9
	(0.042)	(2.35)

[a] Standard errors in parentheses.

The method of harvest, or gear type, reflects some expectation about the past handling of the fish, as well as characteristics that cannot be measured. The default case is trolling. The coefficients show that, on average, fish landed by longliners get \$.241 less per pound in the auction, while handliners' price is not significantly different from trollers, after adjusting for characteristics of the fish.[4] The results are at odds with the simple means of published prices. This can be seen for mean prices in the current data set. Table 4 shows the mean prices and weights of yellowfin by gear type. The explanation must be that the characteristics of the fish capture the apparent premium, not the method of harvest.

Coefficients on bigeye landings, labeled $\Sigma\ W_{BE}$, and similarly named variables represent the influence of landings on prices. These variables are in units of 10,000 pounds to make the coefficients tractable. The bigeye price effect is the largest, showing that an increase of 10,000 pounds in landing per day reduces the price per pound of fish by \$.17. The coefficient on $\Sigma\ W_{BE}$ is significantly different from zero at a better than 99.9% level of confidence. The coefficient on $\Sigma\ W_{YF}$ is also negative (−0.075), suggesting that there is some depression of price, but it is smaller than the bigeye coefficient. The albacore coefficient (0.008) is not significantly different from zero. This is quite sensible, because most albacore goes to the canned market and the canned

[4] If one held a prior that handliners had a lower price than trollers, then a one-tailed test would be correct and one would look for a critical region for a t-statistic of −1.645 or less for 95% confidence. In that case, we might say that handliners do get lower prices. But a more reasonable prior would be that handliners get a lower price than trollers.

albacore sector can take very large quantities without any price effects. The albacore result is consistent with the presence of a large world market for albacore. While many albacore go into outlets for fresh fish, equilibrium requires that prices are equal in both markets.

Two variables are important for policy considerations: the influence of W_{whl} and the differential price effects of the method of handling: D_{HL} and D_{LL}. The size of the fish is an important determinant of the price of the fish. Consequently, fish that grow bigger are disproportionately more valuable, not in the sense of more pounds but more value per pound. Thus, fish that can be saved potentially provide higher value, even though saving fish means harvesting them at a later date. The value of fish harvested in the future must be discounted by the market rate of interest to determine its current market value. For example, a fish harvested one year from today would be worth $W_1P_1/(1 + r)$ in present discounted revenues, where W_1 is the weight of the fish in pounds in one year, P_1 is the price received per pound in one year, and r is the discount rate. If W_1P_1 grows faster than the interest rate, saving fish makes sense. The common property failure is clearly evident here, for individual fishermen cannot capitalize on the natural growth of fish by harvesting in the future what they decline to catch currently.

The categorical variables for method of capture or gear type suggest that fish caught by trollers are more valuable to consumers than fish caught by handliners or longliners. This does not necessarily mean that they are more valuable socially, because that depends in part on the cost of harvesting. However, other things being equal, it suggests consumers, the ultimate users of the resource, are not indifferent to the allocation of catch to harvesting sectors. This would be a potentially important influence with the advent of an efficient management regime.

Grading versus Characteristics

The role of buyers in the auction for fish is to grade fish on the basis of their characteristics, and to bid for fish based on the grade of the fish. In the data set gathered by Bartram and colleagues, the authors also graded the fish. The availability of these grades is a special characteristic of the dataset. Only the two buyers impute the grades in this dataset. In the course of auctions all buyers grade the fish, some doing so explicitly and some implicitly. In the analysis below we take advantage of the grading to explore the degree to which the grades are "sufficient statistics" for the price of fish. That is, what proportion of the variation in the price of fish is explained by the grades and to what extent do the characteristics provide additional information about the prices? A plausible hypothesis is that grading is a proxy for the latent characteristics of fish. Characteristics that are easily observed, such as species or whether the fish is whole, need not figure into the grading. We examine this issue by estimating a series of increasingly inclusive models, beginning with a model that uses only the grades.

To test for the effect of grading, we need to develop a slightly more complete specification of the hedonic model. The basic hedonic model presented in equation (3) does not model days explicitly, although the fish are sold on different days. In the basic hedonic model, landings exhibit more variation across days than any other exogenous variable that would be collinear with days. To be more complete in accounting for all the variation across days that is not measured by the characteristics of fish, we estimate a dummy variable model. A separate intercept for each of the twenty-three days represents the unmeasured events for each day of the survey. Unmeasured variables in addition to landing that vary from one day to the next include weekend versus week day, exchange rates, international market fish prices, and weather. In some cases these covariates are difficult to measure. Since we have no direct interest in the coefficients of the covariates, we simply include a different categorical variable for each day to measure their effects. While the dummy variable model is more complete, the estimated equation is virtually identical to one in which the dummy variables for days are replaced by landings.

The dataset reveals the following six grades for fish, where the lower the number the higher the grade[5]:

Grade	Number of Fish	Percentage in the Grade
0	395	4.6
1	684	7.7
2	4,140	47.9
3	1,052	12.2
4	1,995	23.1
5	389	4.5

[5] In a longer report (McConnell, Strand, and Curtis), we explain how the grades are derived from Bartram and colleagues.

To understand the influence of grading versus characteristics, we estimate the model sequentially, from the simplest model with grades only, to a model with grades and species, then the more complicated model with grades, species and physical characteristics of the fish. This sequential estimation shows how partially specified models work, compared to the complete model. Table 5 presents the three basic models. The first model, with grades only, explains almost 39% of the variation in fish prices. The default grade is GR_5, the lowest (worst) grade. Hence, the coefficients on the grade variables represent the increment in the price of fish over the lowest grade. The coefficients on the grades should decline monotonically from GR_0 to GR_4. The grades are all significantly greater than zero, and they have the correct order, except for GR_2. These coefficients show that GR_0 gets a premium in price of \$2.58 over the lowest grade. Although GR_2 is higher than GR_5 by \$.884, it receives a lower increment than GR_3, which has a price higher by \$1.332. This is simply bias as a consequence of an incomplete specification.

The obvious set of variables to include next is the species—the categorical variables for yellowfin and bigeye. Albacore will be the default case. The coefficients including both grades and species are found in column 2 of table 5. When species are included, the grades are sorted out in a logical way, so that the coefficient on each lower grade is significantly

Table 5. Dummy Variable Hedonic Model of Tuna Prices

Variable	Grade Only (t-statistic)[a]	Grade and Species (t-statistic)	Grade, Species, and Physical Characteristics (t-statistic)
GR_0	2.580	3.078	2.646
	(37.66)	(53.24)	(47.41)
GR_1	2.487	2.630	2.237
	(40.45)	(50.93)	(44.26)
GR_2	0.884	1.742	1.508
	(17.39)	(38.91)	(34.68)
GR_3	1.332	1.285	1.115
	(23.54)	(27.18)	(24.60)
GR_4	0.496	0.839	0.70
	(9.36)	(18.30)	(16.37)
D_{YF}		1.362	1.216
		(55.93)	(42.40)
D_{BE}		1.428	1.353
		(53.09)	(51.87)
$BURN_0$			−0.185
			(−1.82)
$BURN_2$			−0.172
			(−1.19)
$BURN_3$			−0.131
			(−0.82)
W_{whl}			0.005
			(22.35)
D_{HGUT}			0.673
			(16.73)
D_{WHL}			0.917
			(33.58)
D_{LL}			−0.114
			(2.76)
D_{HND}			−0.110
			(2.44)
D_{NFAT}			0.043
			(0.64)
D_{FAT}			0.700
			(10.60)
Observations	8,635	8,635	8,635
$\bar{R}^2$	0.39	0.57	0.64

[a] Under the null that the parameter equals zero.

greater than zero but significantly less than the next higher grade. Consequently, including the species corrects the anomaly in the coefficients on grades. Furthermore, the coefficients on the species conform with expectations, in that bigeye is the highest and yellowfin is the second highest. When the species are included, the model explains about 57% of the variation in price.

The third column of table 5 includes the physical characteristics—the degree of burn, the fat content, and the means of handling. The resulting hedonic estimates imply that these variables are attempting to explain the same phenomena that graders have already observed and incorporated into the grade. The burn variables are not ordered in the right way and individually they are not significantly different from zero. Likewise, the coefficient on the variable for no fat, NFAT, is not significantly different from zero. However, the variables for handling the fish and method of landing are all significant. Further, the W_{whl} variable indicates a premium for larger fish, at $.005 per pound, independent of grade. As in the previous model of hedonic prices, trolling is the default method of landing so that D_{LL} and D_{HND} represent the reduction in price over troll-caught fish. Although these physical characteristics appear significant, they only increase the explanation of the variation in price by seven percentage points, from 57% to 64%.

A formal test of the significance of the additional variables is an F-test. This is a test of the null hypothesis that all the parameters on the additional variables are zero. Table 6 gives three tests for the inclusion of the additional sets of variables. In the latter two models of table 5, "Grade and Species," and "Grade, Species, and Physical Characteristics," we can reject the hypothesis that the coefficients on the additional variables are all equal to zero. This is true even when we consider the kinds of characteristics that go into grading, that is, fat content and the degree of burn on the fish.

Table 6. Tests of the Effect of Physical Attributes on Tuna Prices

Variable set	F-statistic[a]
D_{YF}, D_{BE}	1462.0
$BURN_0$, $BURN_2$, $BURN_3$, W_{whl}, D_{HGUT}, D_{WHL}, D_{LL}, D_{HND}, D_{NFAT}, D_{FAT}	149.6
$BURN_0$, $BURN_2$, $BURN_3$, D_{NFAT}, D_{FAT}	31.8

[a] Critical values of the F-statistic at the 1 level of significance are, respectively, $F_3^{0.01} = 3.78$, $F_5^{0.01} = 3.02$, $F_{10}^{0.01} = 2.32$.

These tests isolate in a quantitative way what happens in the grading. As is described in Bartram and colleagues, grading is principally about the physical qualities of the fish, which are not easily observed or assessed. Fish are graded primarily on their overt characteristics such as species, size and physical defects, potential shelf life (which is based on temperature), body condition, muscle texture and bloodline, and fishing and storage methods; and an evaluation of muscle quality based on texture, color, clarity, and fat content. Additional quality is attributed to fish-based size, form, species, and the method of harvesting. However, even these variables do not explain as much variation in the price of fish as the grades.

The Impact of Landings

In the initial hedonic model, landings were introduced as simply another variable that influenced the price of tuna. In the previous section, we used a dummy variable model, which captures the influence of daily events such as landings through a dummy variable for the day. In this section we are more systematically interested in the market implications of landings on tuna prices. If the Hawaii market were fully integrated into the world market for tuna, then daily landings would not influence local prices. Three conditions are required for landings in Hawaii not to influence Hawaii prices. First, some landings naturally go into an international market. Second, landings in Hawaii must not be big enough to influence world prices. Third, handling and transportation capacity in Hawaii must be sufficient to accommodate increases in landings without raising costs or creating bottlenecks. Perishability is important to the extent that the fish are marketed in fresh or frozen form. Capacity to move the product quickly matters when the fish can deteriorate. We compare the dummy variable model with a model in which landings replace the day-specific categorical variables.

The influence of landings on price is important for fisheries development and policy. From the development perspective, plans for increasing supply in Hawaii will not necessarily benefit the commercial harvesters if landings depress prices, unless harvests increase proportionately more than prices decline. From the point of view of fisheries policy, it is important to consider the price effects of seasonal and area restrictions on fisheries when these restrictions reduce harvest.

We estimate the effect of landings based on the specification in the last column of table 5, only replacing the daily dummy variables with landings. Our focus is on the landings coefficients. The coefficients, mean daily landings and flexibilities, are given in table 7. An intuitive indication of the role of landings versus the dummy variable models can be gained by comparing the percent variation in price explained, the adjusted R^2. With the dummy variable models, along with the other variables, the model explains 63.6% of the variation in price. When the landings are substituted for the dummy variables for the days, the model explains 62.3%. Consequently, it appears that the day-specific dummy variables are accounting chiefly for changes in landings.

The flexibilities, percent changes in the price of all fish from a 1% change in landings of species i, are calculated as $(\bar{L}_i/\bar{P})\partial P_i/\partial L_i$, where the bars indicate means for landings or price over the sample period. The last column contains the flexibilities. These are flexibilities in the sense that they represent the percent response of price to a percent increase in landings. In principle, this response in price can occur because of insufficient capacity to ship fish out, because local consumers in Hawaii can only be induced to consume more fish with a lower price, or because Hawaii supply on the world market is large enough to influence world price. It seems unlikely that Hawaii supply influences world prices, so the flexibilities probably stem from local conditions. This is borne out by the size of the flexibilities, which are generally quite low, the largest being for bigeye. The coefficient on albacore, which is positive but not significantly different from zero, can be understood in terms of the world market. Since albacore typically goes into canning, it enters a very large world market. The coefficient not being significantly different from zero means that the market can accommodate large quantities of albacore without depressing the price. The world market effect holds even though much albacore now goes into markets for fresh fish because the fresh market for albacore must equilibrate with the world market for canning.

Conclusions

This article has demonstrated that the characteristics of individual fish influence market price in a manner consistent with hedonic prices. The physical characteristics of fish determine the ex-vessel price. Not only do the characteristics have the right qualitative effects, the numerical values are also intuitively sound. These are the virtues of empirical analysis based on a large sample in an organized and orderly market.

The presence of the hedonic effects is an empirical finding consistent with the adage that quality matters. However, the specific findings have implications for fisheries management and for harvesting behavior. There are several findings of interest to fisheries managers. One concerns the influence of the size of the fish on the market price. As fish size gets large, the equilibrium price per pound rises. This is the market providing information on the value of saving fish. When combined with biological information on the growth and mortality rates of fish, one can calculate the optimal time to harvest tuna. The hedonic price effect is simply another piece of information suggesting that the search for rights-based fishing institutions would pay off (see Homans and Wilen). A second specific finding is that the price for troll-caught fish is higher than for other gear,

Table 7. Effect of Landings on Tuna Prices

Daily Landings of Species	Estimated Coefficient (t-statistic)	Mean Landings (10,000 lbs.)	Flexibility at Mean Landings and Prices[a]
ΣW_{YF} (yellowfin)	−0.086 (−5.38)	0.649	−0.035
ΣW_{BE} (bigeye)	−0.187 (−9.84)	0.624	−0.074
ΣW_{AL} (albacore)	0.019 (0.71)	1.21	Coefficient not significantly different from zero

[a] The mean price per pound of all fish over all days of the auction was $1.58.

suggesting that other things being equal, this gear type provides higher value. The flexiblities provide some insight into the potential for management of fish stocks. They show the value of additional harvested fish, as well as the increased revenue that can be gained by spreading out the harvest of fish over several days.

The price flexibilities of yellowfin and bigeye give evidence that additional landings lower prices. This suggests that a carefully coordinated harvest policy could smooth prices for producers. The coordination problem here is rather severe, since trip length for many vessels is stochastic, depending on weather and cumulative catch. Furthermore, there are potentially adverse welfare effects on the consumer side, because consumers may have higher aggregate consumer surplus when prices vary. This relates back to the long-debated issue in agricultural supply and policy, originally raised by Waugh in 1944 (Waugh 1944) of whether consumers benefit from price instability. Just, Hueth, and Schmitz (chap. 11) summarize the arguments, showing that consumers gain from price instability if they can adjust their consumption when prices change. Since this is the case for fisheries, it is reasonable to conclude that a policy of stabilizing prices might benefit harvesters, but probably does not benefit consumers.

Of direct interest to harvesters are the findings about fish form. Whole fish provide the highest value. Harvesters who are able to care for their fish sufficiently well to preserve the whole form will get a higher price for their product. Additional quantitative information on the partial effects of fishing practices on prices received may provide the impetus necessary to improve traditional harvesting practices and enhance the overall welfare generated from ocean fisheries.

[Received April 1998; accepted May 1999.]

References

Anderson, J.L., and Y. Kusakabe. *Analysis of the Japanese Salmon Market.* Vancouver BC: Canadian Department of Fisheries and Oceans, Economic and Commercial Fisheries Rep. No. 56, 1989.

Anderson, J.L., and P. Brooks. *Conjoint Analysis of the New England Salmon Market.* Report prepared for Canadian Department of Fisheries and Oceans, Vancouver BC, 1986.

Bartram, P., P. Garrod, and J. Kaneko. "Quality and Product Differentiation as Price Determinants in the Marketing of Fresh Pacific Tuna and Marlin." Southwest Fisheries Center 96-06, Joint Institute for Marine and Atmospheric Research 96-304, University of Hawaii, 1996.

Bierlen, R., and O. Grunewald. "Price Incentives for Commercial Fresh Tomatoes." *J. Agr. and Appl. Econ.* 27(July 1995):138–48.

Blomo, V., J. Nichols, W. Griffin, and W. Grant. "Dynamic Modeling of the Eastern Gulf of Mexico Shrimp Fishery." *Amer. J. Agr. Econ.* 64(May 1982):475–82.

Brester, G.W., P. Lhermite, B.K. Goodwin, and M.C. Hunt. "Quantifying the Effects of New Product Development: The Case of Low-Fat Ground Beef." *J. Agr. and Resour. Econ.* 18(December 1993):239–50.

Brown, J.E., D.E. Ethridge, D. Hudson, and C. Engels. "An Automated Econometric Approach for Estimating and Reporting Daily Cotton Prices." *J. Agr. and Appl. Econ.* 27(November 1995):409–22.

Cropper, M., L.B. Deck, and K.E. McConnell. "On the Choice of Functional Form for Hedonic Price Functions." *Rev. Econ. and Statist.* 70(November 1988).

Espinosa, J.A., and B.K. Goodwin. "Hedonic Price Estimation for Kansas Wheat Characteristics." *W.J. Agr. Econ.* 16(July 1991):72–85.

Gillmeister, W.J., R.D. Yonkers, and J.W. Dunn. "Hedonic Pricing of Milk Components at the Farm Level." *Rev. Agr. Econ.* 18(May 1996): 181–92.

Golan, A., and H. Shalit. "Wine Quality Differentials in Hedonic Grape Pricing." *J. Agr. Econ.* 44(May 1993):311–21.

Homans, F.R., and J.E. Wilen. "A Model of Regulated Open Access Resource Use." *J. Environ. Econ. and Manage.* 32(January 1997):1–21.

Just, R.E., D.L. Hueth, and A. Schmitz. *Applied Welfare Economics and Public Policy.* Englewood Cliffs NJ: Prentice-Hall, 1982.

McAfee, R.P., and J. McMillan. "Auctions and Bidding." *J. Econ. Lit.* 25(June 1987):699–738.

McConnell, K.E., I.E. Strand, and R. Curtis. "An Analysis of Auction Prices of Tuna in Hawaii: Hedonic Prices, Grading and Aggregation." Southwest Fisheries Center 98-03, Joint Institute for Marine and Atmospheric Research Contribution 98-317, University of Hawaii, 1998.

Sylvia, G., and S. Larkin. "Wholesale, Firm-Level Demand for Whiting Products: A Multi-Attribute, Multi-Sector Analysis" *Amer. J. Agr. Econ.* 76(December 1994):1242.

Tronstad, R., L.S. Huthoefer, and E. Monke. "Market Windows and Hedonic Price Analyses: An Application to the Apple Industry." *J. Agr. and Resour. Econ.* 17(December 1992): 314–22.

Wang, S.D., and C.B. Kellogg. "An Econometric Model for American Lobster." *Marine Resour. Econ.* 5(Spring 1988):61–70.

Waugh, F. "Quality Factors Influencing Vegetable Prices." *J. Farm Econ.* 10(May 1928):185–96.

Waugh, F. "Does the Consumer Benefit from Price Instability?" *Q. J. Econ.* 58(August 1944):602–614.

Wirth, F.F., C.K. Halbrendt, and G.F Vaughn. "Conjoint Analysis of the Mid-Atlantic Food-Fish Market for Farm-Raised Hybrid Striped Bass." *S.J. Agr. Econ.* 23(July 1991):155–64.