

# Portfolio Analysis for Optimal Seafood Product Diversification and Resource Management

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Future harvests from commercial fish stocks are unlikely to increase substantially due to biological and regulatory constraints. Developing alternative sets of processed seafood products is one strategy for increasing welfare while managing the risks inherent in a variable and renewable natural resource. To quantify the risk-benefit tradeoffs of alternative strategies, a portfolio decision framework is embedded into a multi-period bioeconomic model. The model is used to generate an efficient portfolio frontier to estimate possible rent dissipation from status quo management. Frontiers are also generated for seafood processors and brokers. Implications for the different industry agents are discussed.

*Keywords:* bioeconomic analysis, dynamic optimization, Markowitz, Pacific whiting, portfolio analysis, resource management, seafood processing

## Introduction

Risk-averse investors seek to reduce uncertainty in the expected returns from a portfolio of assets. Markowitz (1952, 1991) provided a means to quantitatively compare potential portfolios and select those with minimum risk given an expected level of return (i.e., the efficient portfolios). Following Markowitz's 1952 seminal article, a large body of literature on portfolio analysis has focused on the securities markets for which the theory was originally developed. Portfolio theory has also been extended to various types of assets including agricultural crops (Heady; Collins, and Barry; Stovall) and natural resources (Mills and Hoover). The most common agricultural applications evaluate risk-return tradeoffs associated with crop diversification practices (Hazell) and dynamic crop planting decisions (Burt and Johnson). The portfolio analysis approach, however, is also applicable to downstream market segments including the food processing sector. For example, processors must decide how to cut, clean, and package a fresh fruit or vegetable. Despite similarities in the decisions faced by investment managers and food processors,

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to our knowledge portfolio theory has not been applied to food processing in general or fish processing specifically.

Increasing the economic stability of the seafood processing sector by reducing the risks associated with sales in output markets can indirectly reduce the financial risk in the harvest sector, thereby sustaining the success of a fishery. By producing a more diverse portfolio of products, processors can accomplish two objectives. First, they can maximize profits through a wider variety of production alternatives that can be matched with the intrinsic characteristics of the raw product. In effect, processors would be positioned to change the composition of output products—including fish paste (surimi), frozen individual fillets, or frozen fillet blocks—by altering the freezing method, portion type and size, and/or degree of processing. This production strategy can increase the profits or reduce the risks associated with seasonal variability in the biological characteristics of the raw input product. Second, seafood markets can be extremely volatile due to both supply and demand variability including seasonal and annual changes in resource stocks, harvests, and output market prices. Access to a larger number of production alternatives is one strategy producers can adopt to address these types of economic risks.

Aside from documenting the effects of diversification at the broker and processor levels, portfolio analysis also provides an analytical tool for policy makers and natural resource managers given their direct and indirect influence on private-sector business behavior (Jensson). For example, seafood processors often depend on uncertain supplies of commercially harvested wild species. Policy makers can control harvest levels and geographic, seasonal, or inter-annual allocations, factors which can directly influence processing costs and production yields as well as indirectly influence the choice of output products, output prices, and diversification strategies.

Understanding how seafood firms manage risks within the opportunities and constraints imposed by public policy is critical for developing management strategies designed to maximize public welfare. This is especially relevant for fisheries because current legislation requires that fisheries be managed to maximize national benefits while reducing risk, particularly in relation to conserving biological stocks.

To fully evaluate the risk-return tradeoffs from portfolio diversification in seafood processing, optimal portfolio frontiers are generated for the Pacific whiting (*Merluccius productus*) fishery using three alternative benefit functions representing the possible objectives of different interest groups. The first approach (the seafood broker scenario) is a direct application of portfolio theory from the finance literature in which diversification strategies are compared based on net returns per unit of output production. This approach is representative of seafood brokers who facilitate transactions between processors and wholesale distributors and bear no additional costs associated with possession or speculation. Unlike other market players, brokers are paid on a percentage of the value of each unit of production. And unlike the processor or resource manager, the “myopic” broker’s decisions are based only on units of output, rather than the opportunities associated with raw input product, harvest, or stock of resource capital.<sup>1</sup>

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<sup>1</sup> Brokers provide a significant link between processors and retail distributors in the marketing chain for whitefish species (Sylvia). Most of these species are regulated using open-access management strategies. Open access tends to generate greater variability in resource stock and harvests, and is characterized by greater policy uncertainty than more flexible management systems such as individual transferable quotas. Such strategies are inconsistent with institutions that support efficient vertical integration or long-term contracting with downstream market sectors including retail or food service firms. Under more efficient institutional arrangements (e.g., property rights), “myopic” brokers would play a less important role.

In the case of unit returns, Markowitz (1952) argued that investors are concerned with both the expected return ( $R$ ) and the variance of returns ( $V$ ) for a given asset or portfolio of assets. Because  $V$  is an “economic bad” for risk-averse investors who require a higher return for investing in higher variance assets, a tradeoff between  $R$  and  $V$  results. This Markowitz or full-covariance model was developed to generate  $R$ - $V$  combinations, among which investors could choose their  $R$ - $V$  preferences (Markowitz 1952, 1991; Alexander and Francis).

The second approach (the fish processor scenario) compares diversification strategies based on total expected net income resulting from a specified input (catch) level. Under this scenario, it is assumed fish processors attempt to maximize net income, which is the expected return, given a predetermined quantity of fish. In doing so, they incorporate expected prices, processing costs, market risk, and production yields into their production decisions. The explicit inclusion of production yields is notable with seafood processing because yields can range from approximately 20% for surimi (a flavorless, odorless protein paste used to produce imitation seafood products) to nearly 90% for minimally processed whole fish (Jensson). In the Pacific whiting fishery, the processing sector incorporates the harvest sector as all operations are considered vertically integrated for quota allocation purposes (Pacific Fishery Management Council).<sup>2</sup> Thus, this scenario generates a frontier for seafood processors, representing the tradeoff between net income and risk for a given quota allocation.

The third approach (the resource manager scenario) links dynamic stock characteristics and resource management objectives with fish processing diversification strategies. By embedding a portfolio decision framework within a dynamic bioeconomic model, it is possible to determine both the efficient product mix and the optimal management plan in a single simultaneous framework. There are several notable features of this approach. First, fish characteristics vary intra-seasonally and affect production yields and final product price. Second, the model incorporates expected price and cost variability which is product specific. Third, the efficient portfolio frontier reflects the rent-maximizing tradeoffs of alternative processing strategies. These tradeoffs provide resource managers with the expected economic outcomes of alternative management plans. Although economic effects are not the sole or primary concern for managers of the Pacific whiting resource, predicted economic effects have affected, for example, design of fishing seasons and quota allocations (Larkin and Sylvia).

A comparison is then made of the optimal frontiers and portfolios generated from benefit functions representing each of the three interest groups described above—seafood brokers, fish processors, and resource managers. Comparisons with the current portfolio and resulting estimates of regulatory rent dissipation are also presented. The study concludes with a summary discussion, with specific remarks considering further potential use of portfolio theory for addressing a wide range of risks associated with marine resource management, including the integration of private and public decision making.

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<sup>2</sup> For management purposes, the fishery is composed of two sectors: (a) factory trawlers that harvest and process at sea, and (b) shore-based processors that receive fish from numerous smaller trawl vessels.

## Modeling Approaches

### Seafood Broker Scenario

Given  $n$  assets ( $i$  product forms), the proportions invested in (i.e., the share directed toward the production of) each asset,  $X_i$ , must sum to one:

$$(1) \quad \sum_{i=1}^n X_i = 1.$$

Using the weighted sum of the expected returns of the individual assets, represented by the mean return  $\bar{r}_i$ , the expected rate of return for the portfolio is denoted by:

$$(2) \quad R = \sum_{i=1}^n X_i \bar{r}_i.$$

With the Markowitz model (Markowitz 1952, 1991), the variance of a given portfolio,

$$(3) \quad \sigma^2 = V = E \left( \left( \sum_{i=1}^n X_i r_i - R \right)^2 \right) = \sum_{i=1}^n \sum_{j=1}^n X_i X_j \sigma_{ij},$$

can also be determined with  $\sigma_{ij}$ , the variance-covariance of past returns between assets  $i$  and  $j$  ( $i, j = 1, 2, \dots, n$ ).

Covariances between assets play an important role in decreasing the variability in the return generated by all assets in the portfolio. Because  $V$  is a weighted average of the variances and covariances of the included assets,  $V$  declines as the correlation between assets decreases. Thus, a low-return product form might be an attractive alternative if its returns are inversely correlated with the returns of other potential product forms.

The  $R$ - $V$  combinations reflecting the tradeoff between returns and risk are derived by minimizing the variance of the portfolio subject to a given level of expected unit return (covering the range of possible returns) and the adding-up constraint. In practice, unit return frontiers are constructed by using proportional returns. In this case, the unit return is calculated per pound of finished product,

$$(4) \quad r_i = p_i - c_i^T,$$

using the observed unit price ( $p_i$ ) and total costs of production ( $c_i^T$ ) including raw product costs ( $c^r$ ), other variable processing costs ( $c^v$ ), and fixed costs ( $c^f$ ) for each product form. Efficient portfolios lie on the concave portion of the frontier and represent minimum risk for a given expected rate of return (or conversely, represent the highest expected return for a given level of risk). In summary, this frontier is generated by minimizing equation (3) subject to equations (1) and (2).

### Fish Processor Scenario

Net income ( $I$ ) in the short run—i.e., a single day, which is applicable to processors—is calculated by summing the total income from each product form:

$$(5) \quad I = \sum_{i=1}^n Q_i^F (p_i - c_i^v),$$

where  $Q_i^F$  represents the total quantity of product form  $i$ , and the term in parentheses represents the corresponding net unit return.

Because output quantities are the results of the efficiency of the production process and are not decision variables, the quantity of raw fish that is available and directed toward producing different products needs to be explicitly included. To that end, the quantity of raw fish available in weight ( $q$ ) is a constraint in this scenario:

$$(6) \quad q = \sum_{i=1}^n Q_i^R.$$

This quantity is disaggregated for use by processors into the quantity of fish landed that is directed toward the production of product form  $i$  ( $Q_i^R$ ). To account for the effect of production yields (also known as product recovery rates) on the selection of products to produce,  $Q_i^R$  is multiplied by the yield for product form  $i$  ( $\gamma_i$ ), where  $0 < \gamma_i < 1$ , to determine the total quantity of product  $i$  available for sale:

$$(7) \quad Q_i^F = \gamma_i Q_i^R.$$

Two additional equations are needed to determine the portfolio distribution of products. The quantities of the final products must be summed to determine the total quantity of final products produced,  $Q^T$ :

$$(8) \quad Q^T = \sum_{i=1}^n Q_i^F.$$

The output portfolio enters the model through the following equation:

$$(9) \quad Q_i^F = X_i Q^T.$$

The net income frontier is generated by maximizing the expected net income (5) given a specified level of risk subject to equations (3) and (6)–(9). The model is solved over a range of possible risk levels to construct the maximum expected net income ( $I$ ) portfolio frontier.

### Resource Manager Scenario

An age-structured model predicts the number of fish harvested ( $N$ ) in each time period. Fish age ( $a$ ) ranges from 2 to 15 years. Time ( $t$ ) is tracked monthly across years. Stock size is determined by the previous stock size and the total mortality rate ( $Z$ ), which is composed of natural mortality ( $m$ ) and fishing mortality ( $F$ ). Fishing mortality is determined by the harvest rate, selectivity of each cohort to fishing pressure ( $sel$ ), and a variable that allocates effort within each season. The harvest rate is determined by the size of the spawning biomass ( $SB$ ) and an adjustment factor, which is the ratio of the ideal harvest rate ( $f^*$ ) to the corresponding “ideal” spawning biomass ( $sb^*$ ). The spawning biomass is the weight of the sexually mature females calculated by multiplying the stock size ( $N$ ), fish weights ( $w$ ), proportion of females by weight ( $pf$ ), and the proportion of females that are sexually mature ( $pm$ ). The explicit biological, harvest, and processing equations are presented in table 1.

**Table 1. Glossary of the Model Components Used in the Resource Manager Scenario**

Variable	Equation <sup>a</sup>
<b>Biology and Harvest:</b>	
Numbers of Whiting	$N_{t+1a+1} = N_{ta} \exp(-Z_{ta})$
Total Mortality	$Z_{ta} = m + F_{ta}$
Fishing Mortality	$F_{ta} = (f \cdot SB_t / sb^*) sel_a M_t$
Spawning Biomass	$SB_t = \sum_a N_{ta} w_{ta} pf_a pm_a$
Landings in Numbers	$H_{ta} = N_{ta} (1 - \exp(-Z_{ta})) (F_{ta} / Z_{ta})$
<b>Processing:</b>	
Production in Weight	$Q_{ii}^F = \sum_a H_{ta} w_{ta} X_{ti} \gamma_{ii}$
Annual Product Form Allocation	$\sum_i X_{ti} = 1$

<sup>a</sup>See text for description of the parameters, which are denoted by lower-case letters. Time, fish age, and product form are denoted by indices  $t$ ,  $a$ , and  $i$ , respectively. For simplicity, time (month and years) is represented by a single index. Separate indices for month and year are used in the programming model to advance the age of each cohort, include a new cohort, and account for annual fixed costs in each year. (See Larkin and Sylvia for further detail.)

The harvest in numbers ( $H$ ) is calculated using the total number of fish, the proportion that die during the period, and the proportion that die from fishing effort. The total quantity of final products produced in time  $t$  is determined by a number of factors including the total number of fish harvested during the period. Other dynamic factors also significantly affect the volume of final products, including the weight of each cohort at the time of harvest, the proportion of fish used to produce alternative product forms, and the production yields. A significant feature of the dynamic model is that it determines optimal production strategies (i.e., product form portfolios) in each time period,  $X_{ti}$ , which are averaged for comparison among scenarios. These portfolios change over time in order to account for the seasonal variation in the weight of individual fish within each cohort and other intrinsic characteristics such as protein and fat content which affect yields and prices.

In a dynamic framework, net income is standardized over time using a monthly discount rate ( $\delta$ ),

$$(10) \quad NPV = \sum_t \sum_i I_{ti} (1/(1 + \delta))^t,$$

where net income ( $I$ ) is redefined over time as:  $I_{ti} = Q_{ii}^F r_{it} - fc$ , such that total costs of production and all fixed costs ( $fc$ ) are included. The objective of the resource manager model is to maximize net present value ( $NPV$ ) subject to the stock dynamics, harvest equation, product form selection, and production equations. The frontier is generated by maximizing equation (10) subject to the biological, harvest, and processing equations in table 1 and different levels of risk associated with allocating the raw fish into the production of alternative product forms [equation (3)]. Due to a lack of sufficient data, the unit returns differ only by month (not year), and the covariance matrix is held constant across all months.

## Data

### *Stock*

Using the Pacific whiting fishery, the inter-year biological dynamics are modeled assuming a three-year time horizon in order to correspond with the stock assessments conducted by the National Marine Fisheries Service (NMFS). Total annual landings, however, are subject to an aggregate quota of 273,800 metric tons (mt) in order to be consistent with the triennial harvest plan and stock assessment schedule (Pacific Fishery Management Council). The specified biological equations and parameters were adapted (and in some instances simplified as described earlier) from Larkin and Sylvia, and from NMFS source documents described therein.

### *Product Forms and Prices*

Prices for six whiting product forms were obtained from the *Fisheries Market News Report* (NMFS). Historical price data were not available for all products because domestic processing and marketing only began in the early 1990s. As there is high correlation between prices of identical product forms processed from similar species due to substitution possibilities at the processor level (Sylvia), the volatility in returns of a whiting product is assumed to equal the volatility experienced by an identical product made from walleye pollock (*Theragra chalcogramma*). Based on this assumption, published monthly prices for six additional non-whiting products were included (i.e.,  $i = 1, 2, \dots, 12$ ). All prices were obtained for a five-year period ending September 1995.

Prices for the non-whiting products were obtained from various issues of the *Seafood Price Current* (Urner Barry). The monthly price data show a correlation coefficient of 0.873 for pollock and cod fillets over the five-year period, which is nearly identical to the 0.869 correlation between pollock and whiting blocks. Breaded products processed from pollock and whiting showed an even higher degree of correlation (0.952). These high correlation coefficients indicate the substitutability among product forms of different species and support the decision to use prices of similar species as a proxy for product forms not currently produced from whiting. Prices were adjusted to the average of market prices observed in September 1995 using the average price difference between species, provided by processors from an industry survey (Tuininga). Table 2 gives a summary of the product forms, their abbreviations used in this analysis, and related price information.

### *Costs*

Costs were obtained through surveys with whiting processors (Tuininga). The reported average variable costs by product form are summarized in table 3. Because costs were not collected over time, producer price indices developed by the U.S. Department of Labor were used to estimate costs over time for labor, ingredients, packaging, and manufacturing overhead. For example, the producer price index for "folding sanitary containers" was used to derive a monthly time series of estimates to correspond with the price data for packaging costs.

At the time of the survey, fixed costs per pound of finished product ( $c_{it-1}^f$ ) averaged \$0.114 and consisted of administrative salaries (\$0.042), interest and depreciation

**Table 2. Product Forms for Portfolio Model Selection**

Abbreviation	Product Description <sup>a</sup>	Lot Size	Species	Average Price (\$/lb.)	Price Adjustment <sup>b</sup> (\$/lb.)	Price Range (\$/lb.)	Source <sup>c</sup>
H&G	Headed and Gutted	5.0 lbs.	Whiting	0.40	-0.03	0.37-0.49	NMFS
BLK	Blocks	16.5 × 4 lbs.	Whiting	0.80	-0.15	0.65-1.18	NMFS
MBL	Minced Blocks	16.5 × 4 lbs.	Pollock	0.43	-0.02	0.39-0.92	NMFS
SUR	Surimi	16.5 × 4 lbs.	Pollock	1.10	-0.23	0.60-2.03	NMFS
LF_A	Layerpack Fillets, skinless	10.0 lbs.	Whiting	0.95	0.00	0.83-1.08	NMFS
LF_B	Layerpack Fillets, skin-on	10.0 lbs.	Whiting	0.74	0.00	0.61-0.83	NMFS
SF2	Shatterpack Fillets, 2-4 oz.	3 × 15 lbs.	Pollock	0.95	-0.35	0.55-1.36	UB
SF4	Shatterpack Fillets, 4-6 oz.	3 × 15 lbs.	Pollock	1.00	-0.35	0.70-1.60	UB
IQF2	Individually Quick Frozen Fillets, 2-4 oz.	Bulk	Pollock	0.95	0.00	0.80-1.40	UB
IQF4	Individually Quick Frozen Fillets, 4-6 oz.	Bulk	Pollock	1.00	-0.10	0.95-1.62	UB
BP_C	Breaded Portions, 2-4 oz. cooked	6.0 lbs.	Whiting	1.10	-0.35	0.97-1.20	NMFS
BP_R	Breaded Portions, 2-4 oz. raw	6.0 lbs.	Whiting	1.05	-0.35	1.00-1.18	NMFS

<sup>a</sup> All products are frozen. All fillets are skinless unless specified otherwise.

<sup>b</sup> Prices were adjusted to match the average market price observed by Pacific whiting processors in September 1995 based on price relationship information provided during the surveys (Tuininga).

<sup>c</sup> NMFS = National Marine Fisheries Service and UB = Urner Barry, for the five-year period ending September 1995.



**Table 3. Raw Product and Other Variable Costs per Finished Pound for Pacific Whiting**

Cost Components	Product Form <i>i</i>								
	H&G	BLK	MBL	SUR	LF_A <sup>a</sup>	LF_B	IQF <sup>b</sup>	BP_C	BP_R
<b>Raw Product</b> ( $\bar{c}_i^r$ ):									
Cost	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fish tax (1.09%)	0.001	0.002	0.002	0.003	0.002	0.002	0.002	0.001	0.001
Total (\$/lb. raw)	0.051	0.052	0.052	0.053	0.052	0.052	0.052	0.051	0.051
<b>Processing</b> ( $\bar{c}_i^p$ ):									
PRR (lb. output/lb. raw) <sup>c</sup>	0.54	0.23	0.33	0.16	0.23	0.31	0.23	0.38	0.38
Total (\$/lb. output)	0.09	0.23	0.16	0.33	0.23	0.17	0.23	0.13	0.13
<b>Labor and Benefits</b>	0.06	0.25	0.05	0.12	0.40	0.37	0.25	0.50	0.50
<b>Ingredients</b> <sup>d</sup>	0.00	0.00	0.02	0.09	0.00	0.00	0.00	0.14	0.11
<b>Packaging</b>	0.05	0.02	0.03	0.04	0.06	0.06	0.06	0.06	0.06
<b>Manufacturing Overhead</b>	0.05	0.10	0.05	0.13	0.12	0.12	0.12	0.12	0.12
<b>Total</b> <sup>e</sup>	0.25	0.59	0.30	0.69	0.80	0.72	0.65	0.96	0.93

<sup>a</sup> Also represents costs for shatterpack fillets (SF2 and SF4).

<sup>b</sup> Costs are the same for all fillet sizes.

<sup>c</sup> PRR is the "product recovery rate," which is the output quantity divided by the input quantity.

<sup>d</sup> Note, some product forms do not require the use of any ingredients and so have zero costs.

<sup>e</sup> Totals may not equal sum of individual components due to rounding.

(\$0.04), operating expenses (\$0.015), insurance (\$0.01), and technicians (\$0.006). Because fixed costs were indistinguishable across species and product forms, they were allocated equally among all finished products. In the *NPV* scenario, fixed costs (*fc*) totaling \$15 million were included as a lump sum based on findings reported by Radtke.

### *Yield and Cost Seasonality*

Historically, the processing of whiting has not been equally distributed throughout the year due to seasonal migration and open-access harvesting. Harvest and processing have occurred primarily from April through October. Table 4 documents the monthly yields used in this analysis. As evident from table 4, yields vary significantly among the different products, and are expected to have an important impact on net income and *NPV*. For example, 1,000 mt of raw fish could be used to produce 1,186,000 pounds of headed and gutted product (H&G) or only 355,000 pounds of surimi. Table 4 also includes the monthly variable processing costs for each product form, which varied by less than 4% for any given product.

## Results

### *Seafood Broker Scenario*

A nonlinear programming model was developed to solve the full-covariance portfolio model [equations (1)–(4)]. This model and subsequent models were optimized using the GAMS software package with the MINOS solver (Brooke, Kendrick, and Meeraus). A nonnegativity constraint was imposed on the allocations to each product form in order

**Table 4. Pacific Whiting Seasonal Processing Parameters**

Product Form	Month						
	April	May	June	July	August	September	October
<b>Processor Yields</b> ( $\gamma_{it}$ lb. output/lb. raw):							
MBL	0.310	0.320	0.330	0.340	0.340	0.340	0.340
LF_A	0.210	0.220	0.230	0.240	0.240	0.240	0.240
LF_B	0.300	0.310	0.320	0.330	0.330	0.330	0.330
BP_C, BP_R	0.344	0.361	0.377	0.393	0.393	0.393	0.393
H&G	0.510	0.525	0.540	0.540	0.540	0.540	0.540
BLK	0.210	0.220	0.230	0.240	0.240	0.240	0.240
SUR	0.151	0.156	0.161	0.166	0.166	0.166	0.166
SF2, SF4	0.210	0.220	0.230	0.240	0.240	0.240	0.240
IQF2, IQF4	0.210	0.220	0.230	0.240	0.240	0.240	0.240
<b>Variable Cost of Production</b> ( $c_{it}^v$ \$/lb. output):							
MBL	0.313	0.308	0.303	0.299	0.299	0.299	0.299
LF_A	0.821	0.810	0.800	0.791	0.791	0.791	0.791
LF_B	0.723	0.718	0.713	0.708	0.708	0.708	0.708
BP_R	0.942	0.935	0.929	0.923	0.923	0.923	0.923
BP_C	0.972	0.965	0.959	0.953	0.953	0.953	0.953
H&G	0.259	0.256	0.254	0.254	0.254	0.254	0.254
BLK	0.616	0.605	0.595	0.586	0.586	0.586	0.586
SUR	0.711	0.700	0.690	0.681	0.681	0.681	0.681
SF2, SF4	0.821	0.810	0.800	0.791	0.791	0.791	0.791
IQF2, IQF4	0.671	0.660	0.650	0.641	0.641	0.641	0.641

to preclude assets from being sold short. This assumption is reasonable for the whiting fishery, as processors have indicated forward contracting is rare (Tuininga). In addition, an upper-bound constraint of 30% was imposed on individually quick frozen (IQF) and shatterpack fillet shares for the 4–6 oz. product size in order to conform with the average size of this whiting species, which is relatively small.

Correlation coefficients of the proportional unit returns described in equation (4) for the 12 alternative product forms ranged from  $-0.51$  to  $0.90$  (table 5). The return of the block product form (BLK) was negatively correlated with the returns of most other products. The H&G return was negatively correlated with the returns of surimi (SUR) and shatterpack fillets (SF2, SF4). Due to their negative correlation coefficients with different product forms, blocks and H&G are likely important products in reducing variation in the expected rate of return (assuming these relationships continue to hold).

Causal explanations for these weak to moderate negative correlations are difficult to determine given the complexity of global whitefish markets, which encompass generic white-flesh fish products such as those produced from Pacific whiting and walleye pollock. Possible reasons may stem from the inverse seasonal supply trends of alternative frozen whitefish products produced in the southern versus northern hemispheres. Other reasons may be related to the distinct markets for which these products are targeted. Spurious correlation is also possible, particularly given that the data cover only a five-year period.

**Table 5. Product Form Correlation Coefficients of Unit Returns**

	H&G	BLK	MBL	SUR	LF_A	LF_B	SF2	SF4	IQF2	IQF4	BP_C	BP_R
H&G	1.00											
BLK	-0.05	1.00										
MBL	0.40	-0.09	1.00									
SUR	-0.05	-0.27	0.81	1.00								
LF_A	0.40	0.13	0.30	0.19	1.00							
LF_B	0.13	0.10	0.36	0.48	0.77	1.00						
SF2	-0.51	0.13	0.29	0.48	0.16	0.20	1.00					
SF4	-0.18	-0.13	0.26	0.36	0.35	0.22	0.78	1.00				
IQF2	0.34	-0.36	0.77	0.64	0.44	0.36	0.34	0.56	1.00			
IQF4	0.20	-0.45	0.52	0.44	0.30	0.15	0.41	0.72	0.90	1.00		
BP_C	0.26	-0.50	0.25	0.18	0.10	-0.07	0.18	0.59	0.60	0.80	1.00	
BP_R	0.66	-0.52	0.54	0.36	0.30	0.12	-0.04	0.38	0.75	0.76	0.80	1.00

Note: The correlations were based on monthly observations from October 1990 through September 1995 ( $n = 60$ ).

The optimal portfolio and associated risk resulting from the variance-covariance matrix of unit returns were generated for unit returns ranging from zero to the highest observed unit return in 0.007 increments. The minimum variance portfolio frontier and associated product portfolios from selected points are depicted in figure 1. The constraint on the production of 4–6 oz. fillets prevented the model from increasing the proportion of these product forms above 30%, explaining in part why the slope decreased when moving to the higher risk and return portfolios.

In general, returns and prices were directly related as expected; low return product forms were associated with low risk and vice versa. High return/high risk portfolios for seafood brokers consist primarily of surimi and IQF fillets. Medium return/medium risk broker portfolios are primarily composed of IQF fillets, blocks, and H&G. Raw breaded portions (BP\_R), H&G, and blocks are present in low return/low risk broker portfolios.

The model selected the production of blocks through a wide range of broker portfolios associated with various levels of risk. This occurred because blocks provide significant risk reduction due to their low or negative covariation with all other product forms, especially IQF fillets and breaded products. The model selects 4–6 oz. IQF fillets rather than shatterpack fillets because of their higher expected return. The model does not select minced blocks, skinless layerpack fillets, or cooked breaded portions because the returns and risk-reducing performance of these product forms are relatively low.

In 1998, whiting processors produced a product mix of 70% surimi, 15% IQF fillets, and 15% H&G (Pacific Fishery Management Council). For comparison, this portfolio is identified in figure 1 as “current.” According to the broker frontier, this production strategy would be characterized as relatively high risk/high return. Risk could be reduced by approximately 10% without sacrificing expected return by changing the product mix to reflect portfolio 10 (i.e., reduce surimi production, discontinue producing H&G, increase the production of IQF fillets, and initiate production of blocks). Alternatively, changing the production mix to reflect portfolios 2 or 3 would increase returns by approximately \$0.07/pound for the same risk. Portfolios on the negatively sloped portion of the frontier (albeit small) would never be selected because the same return could be achieved with less risk by selecting portfolios on the positively sloped segment of the frontier.

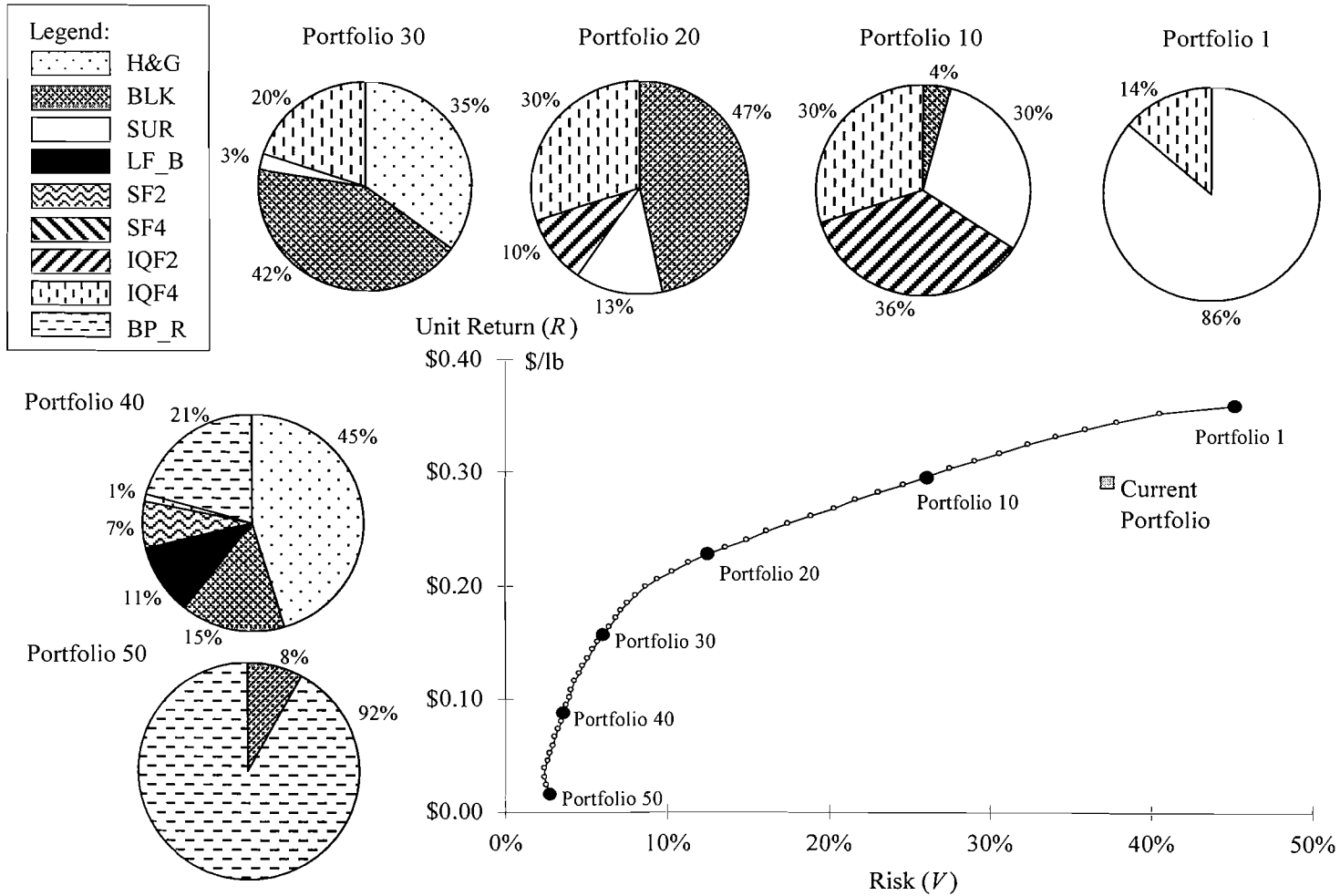


Figure 1. The efficient broker frontier and selected portfolios

### *Fish Processor Scenario*

The efficient processor frontier is generated by maximizing the expected net income [equation (5)] subject to a specified level of risk [equation (3)], which is varied from zero to the maximum possible given the observed variances, and quantity of harvested fish ( $q$ ). The harvest quantity of fish landed was fixed at 1,000 mt, representing approximately the quantity a single plant can process in a day (Libby). The empirical application also includes the nonnegativity constraint on the portfolio shares as used in the previous scenario. Model results are depicted in figure 2 based on a 7% discount rate, which was the official governmental rate at the time of the analyses.

Net income is highest in portfolio 44, which consists of 70% H&G, 27% 4–6 oz. IQF fillets, and 3% 4–6 oz. shatterpack fillets. The variance of this portfolio is 9%, which is below the average risk of all income-maximizing portfolios (25.3%). While the net unit return for H&G (\$0.15/pound) is relatively low compared to 4–6 oz. IQF fillets (\$0.35/pound) and surimi (\$0.41/pound), the higher yield for H&G (54% versus 23%) offsets the lower net return per unit when the total quantity of landed fish is incorporated into the model. In addition, the relatively low covariation of H&G returns with the other product forms (table 5) makes this an important low-risk product form. Overall, the surimi, 4–6 oz. IQF fillets, and H&G product forms comprise some portion of the optimal processor portfolios at all risk levels, although the portfolios include shatterpack rather than IQF fillets at lower risk levels.

The current average portfolio of whiting processors is included in figure 2. The location of this point in risk and net income space indicates (given the prevailing prices, recovery rates, and processing costs) firms may be able to achieve higher profits (\$152,184 versus \$140,000) by shifting production away from surimi and into H&G. A move toward the lower risk portfolios (49 and 50) but with the same return would require shifting production from primarily surimi to H&G and raw breaded portions, and would reduce risk by approximately 36 percentage points. Such a shift would likely depend on the markets for the products in the low-risk portfolios.

When compared to the seafood broker frontier and associated optimal portfolios, the processor frontier also suggests less reliance on surimi but an increase in H&G instead of fillets. Because the harvesting sector is vertically integrated with the processing sector in this fishery, processor output is explicitly considered by resource managers when making quota allocation decisions (Pacific Fishery Management Council). Consequently, this scenario could be used to quantify industry incentives and provide managers with information on the likely outcomes of alternative management plans.

### *Resource Manager Scenario*

The efficient resource manager portfolio frontier is determined by maximizing NPV subject to a specified level of risk ranging from zero to the maximum given the data. For simplicity, each harvest/processing firm is assumed capable of processing all product forms. As current processors have the equipment or can affordably modify their equipment to process each product form considered in this study (Tuininga),<sup>3</sup> this assumption is reasonable.

<sup>3</sup> To consider the case where firms do not currently process whiting or possess the required capacity, the programming model was modified to trigger the purchase of the necessary equipment. The quantity of equipment purchased was determined by the maximum quantity of fish processed in a month. However, because the equation that performed this function was not differentiable, the algorithm in the MINOS solver used by GAMS could not solve this model. Specifically, the discrete choice optimization algorithms were unable to handle the large number of nonlinearities generated by the bioeconomic model. Future development of more sophisticated programming models would allow for the accommodation of discrete and lumpy capital investment (see Tuininga for further detail).

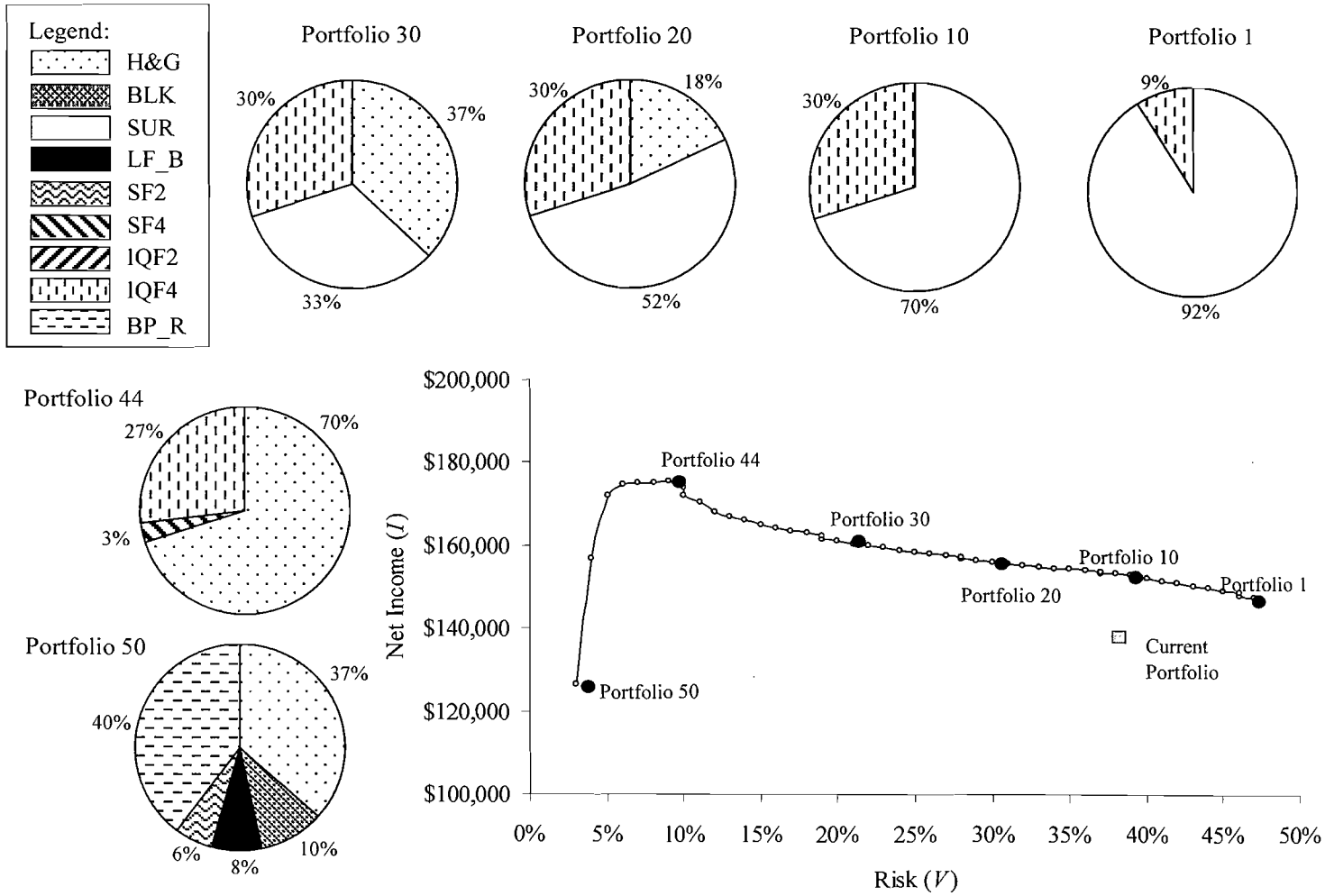


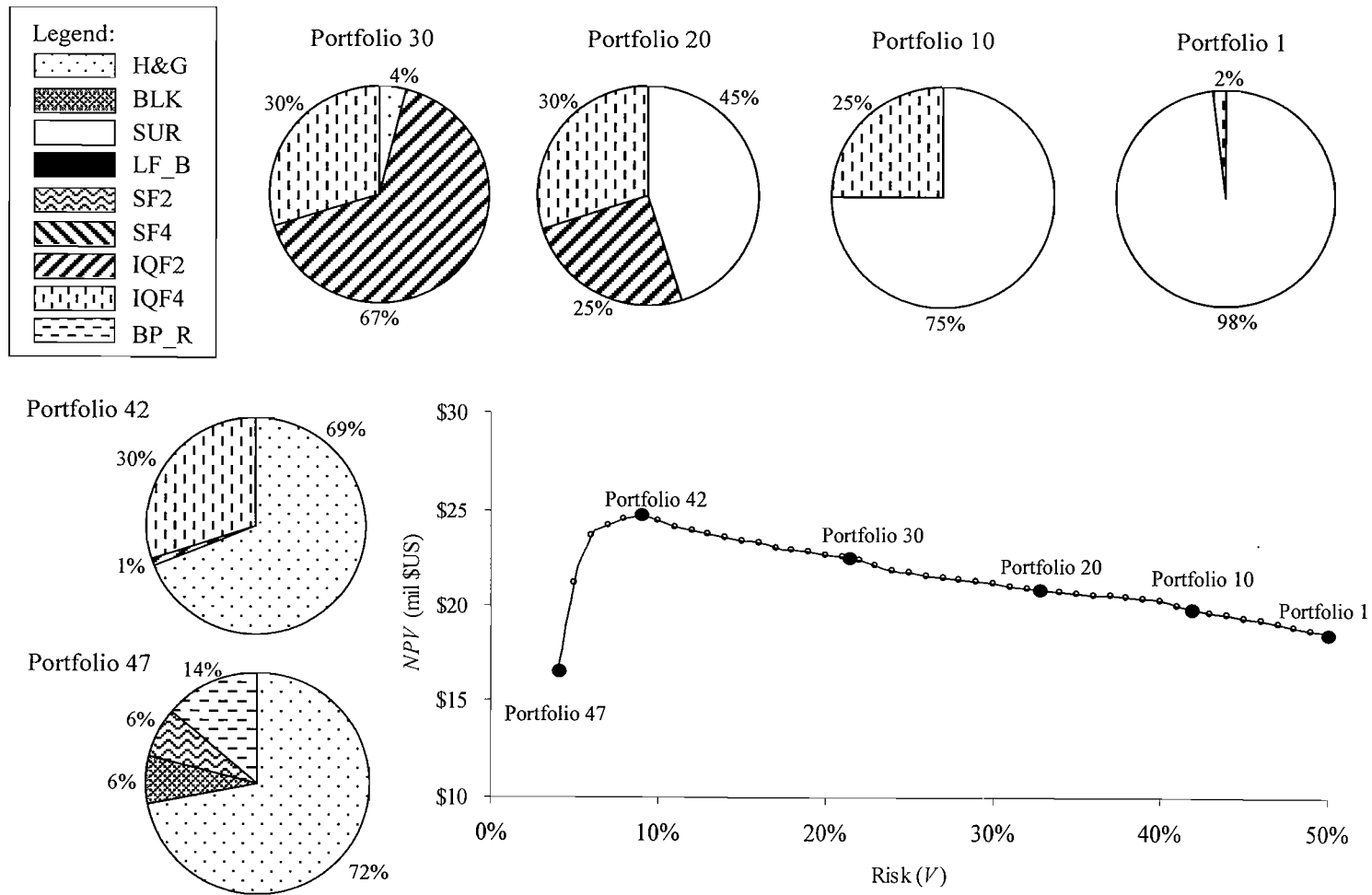
Figure 2. The efficient processor frontier and selected portfolios

The total annual landings quota constraint (273,800 mt) reflects the reality that harvest quantities are determined independently from the expected returns or risks faced by the industry. Additional equations ensure individual product form allocations are nonnegative (as in previous scenarios), the total allocation sums to one, and the existing monthly capacity of the onshore processing sector of 30,000 mt (Libby) is not exceeded. The efficient frontier generated under this scenario is depicted in figure 3, where the sample portfolios are averages over the three-year time horizon.

Low-risk portfolios for resource managers would consist primarily of H&G and 4–6 oz. IQF fillets. The product form with the lowest risk, raw breaded portions, is utilized in the lowest risk portfolio. However, this portfolio would produce the lowest *NPV* over the three-year period (\$16.5 million). Due to the high tradeoff between *NPV* and risk at this low level of risk, processors would likely be inclined to increase *NPV* while only increasing their exposure to risk by a marginal amount. *NPV* is highest (\$24.7 million) at a relatively low level of risk (9%), and is achieved through the production of 69% H&G and 30% 4–6 oz. IQF fillets (portfolio 42). Higher risk management portfolios consist of IQF fillets, decreasing quantities of H&G, and increasing proportions of surimi. Through the middle range of risk, management portfolios contain a maximum of 30% 4–6 oz. IQF fillets due to the production constraint. Where this constraint is binding, *NPV* is maximized by substitution of 2–4 oz. IQF fillets, generating proportionally higher returns due to the interactive effects of increasing product recovery and higher relative prices.

The model optimizes by selecting harvest and processing late in the season (i.e., July through October) given the monthly onshore processing capacity constraint. This optimal delay is due to higher processing yields, which occur later in the fishing season when fish are larger and in better condition. Higher yields generate larger quantities of finished product per unit of raw fish landed, which ultimately reduces the processing costs per finished pound. In addition, the model maximizes *NPV* by producing H&G and IQF fillets at the beginning and end of the processing season, respectively, in each of the three years. In high-risk management portfolios consisting of IQF fillets and surimi, *NPV* is maximized by first producing fillets and then switching to surimi later in the season. In moving along the management frontier from high to low risk, processing strategies make a transition from surimi to H&G production at risk levels above 22%. The processing of raw breaded portions typically accompanies the production of H&G in the lowest risk portfolios. Table 6 summarizes the average intra-season allocation of selected management portfolios.

The resource management frontier in figure 3 is similar to the frontier generated for seafood processors (industry) in figure 2. Despite the similarity, there are significant differences in portfolios between models. Most importantly, the management model incorporates intra- and inter-year stock dynamics, which result in the inclusion (increase) of 2–4 oz. IQF fillets at the expense of surimi and H&G production through the middle range of risky portfolios. The resource management results are particularly relevant given managers have the authority to alter the timing of fishing seasons, affect the speed at which processors operate, and control the allocation of harvests to fishing and processing sectors known to specialize in the production of different products (particularly surimi). When compared to the seafood broker and processor results, the resource manager scenarios predict a larger share of fillets would be optimal.



**Figure 3. The efficient resource manager frontier and selected portfolios**



**Table 6. Selected Intra-Season Portfolios (%) from the Resource Manager Scenario**

Product Form	Month				Average Annual Portfolio
	July	August	September	October	
<b>Portfolio 22:</b>					
SUR	0.0	3.5	49.8	46.8	37.6
IQF2	0.0	73.2	24.1	2.7	32.4
IQF4	45.8	3.9	18.9	31.3	30.0
Total	13.8	26.2	32.2	27.9	100.0
<b>Portfolio 42:</b>					
BP_R	0.0	65.9	34.1	0.0	29.3
H&G	49.8	31.2	19.0	0.0	25.0
BLK	31.6	18.2	31.2	19.0	10.3
IQF2	0.0	0.0	31.2	68.8	5.4
IQF4	0.0	0.0	42.7	57.3	30.0
Total	15.7	29.0	32.5	22.8	100.0
<b>Portfolio 47:</b>					
BP_R	0.0	13.3	66.2	20.5	44.3
H&G	49.8	31.2	19.0	0.0	25.0
BLK	12.3	37.5	18.5	31.8	21.0
IQF4	0.0	8.6	0.0	91.4	9.6
Total	15.0	22.4	38.0	24.6	100.0

### Summary and Conclusions

This analysis has generated risk-return frontiers for interest groups with different benefit functions for the U.S. Pacific whiting fishery. The implications for processing strategies were derived by comparing the current portfolio, risk, and return with the optimal solutions predicted along each frontier. These comparisons quantify the trade-offs of changing product diversification strategies in response to the objectives of alternative interest groups. For resource managers in particular, the comparisons provide a measure of regulatory rent dissipation which is occurring under status quo management. For example, the current production mix of 70% surimi, 15% H&G, and 15% fillets falls below each frontier, indicating the status quo management is suboptimal and inefficient for all interest groups.<sup>4</sup> At the observed risk level, which is relatively high, returns could be increased as much as 16% to 24% depending on the interest group and potential for developing or expanding markets for these product forms.

For seafood brokers focused on product output and unit returns, the optimal portfolios differ markedly from those generated for processors and resource managers at all but

<sup>4</sup> The location of the frontier is affected by the underlying modeling assumptions. The extent to which the model may be misspecified or parameter values have changed (including the discount rate required by the Office of Management and Budget) will affect the level of estimated dissipated rents. Other factors that could affect the position of the frontier include significant processing scale economies, large research and development marketing costs, or aversion to risks associated with future but unknown fisheries management policies.

the highest risk levels. By comparison, broker portfolios would handle a larger number of product forms at all but the highest and lowest risk levels (e.g., portfolio 40 versus portfolios 1 or 50). While H&G is an important product form in low risk/low return portfolios of processors and resource managers, it was included only in the portfolios associated with a relatively small range of risk for brokers. These differences highlight the importance of selecting the market level upon which to base the economic analysis of the fishery.

The share of raw fish directed toward the production of surimi was robust to the alternative benefit functions; surimi dominated the optimal high-risk portfolios and was absent from the optimal low-risk portfolios of brokers, processors, and resource managers. Similarly, large (4–6 oz.) IQF fillets accounted for a stable share of each optimal portfolio at all but the lowest risk levels for each interest group. Two different product forms were included in the optimal portfolios of the lowest risk scenarios—raw breaded portions and, to a lesser extent, blocks. H&G was the only other product form found to be relatively robust to the alternative benefit function specification, although the H&G share was largest and most prevalent in lower risk scenarios for processors and resource managers.

When compared with the current industry portfolio at the processor level, the efficient frontiers reveal the same return can be achieved at lower risk levels by diverting raw fish from surimi to IQF fillets, H&G, and/or blocks. The specific substitute product form depends on the benefit function. Brokers would handle more blocks and IQF fillets, small and large. Processors would produce more large IQF fillets. Resource managers would allocate the annual quota among sectors and dictate the season opening in order to increase the production of IQF fillets. As the risk level is reduced, the H&G product form would enter the optimal portfolios.

Discussions with processors in 1998 revealed that market and product quality development efforts would need to increase in order for H&G and fillet products to realize the predicted profits of increased production (Tuininga). More recent discussions with seafood processors suggest a delayed season opening and cooperative agreements among members of the harvest and processing sectors have contributed to improving product quality and expanding market opportunities for H&G and fillet products. Specifically, they provided greater opportunities for the industry to develop Pareto-efficient risk-management strategies.

At this time, processors plan to decrease surimi production and increase IQF fillets and H&G by 20% to 30%, in part to reduce dependency on price-volatile surimi (Richardson; Libby). Thus, the tradeoffs predicted by the frontiers coincide with the more recent history of the fishery. However, capital stuffing and “race-for-the-resource” strategies by onshore processors induced by regulated open-access management continue to increase opportunity costs associated with more deliberate and balanced harvesting and processing strategies (Larkin and Sylvia).

This work illustrates how portfolio analysis can be used to evaluate the economic effects of product diversification. Although generation of efficient portfolio frontiers and dynamic bioeconomic analysis are well-known tools, their integration provides another approach for evaluating and incorporating the downstream economic effects of resource management policies. For example, the Sustainable Fisheries Act of 1996 requires policy makers to consider the effects of management decisions on fishing communities potentially dominated by fish processing plants, especially in smaller coastal ports.

The portfolio approach is particularly relevant for understanding and improving management of the U.S. Pacific whiting fishery, given the allocation of the annual quota among industry sectors specializing in the production of different product forms which will optimally vary throughout the season (Larkin and Sylvia). In addition, the increasing emphasis on addressing problems associated with industry stability, species substitutability, and implementing biologically related precautionary management suggests a range of opportunities in developing and applying additional risk-based approaches for fisheries managers.

Increasing the economic stability of the processing sector by reducing the risk associated with sales in the output markets can indirectly reduce market variability in the fishing sector and help sustain the development of the fishery. By producing a more diverse portfolio of products, processors can specifically accomplish two objectives. First, they can maximize expected profits through a wider variety of production alternatives that can be matched with the intrinsic characteristics of the raw product. In effect, processors would be positioned to change product forms to best address the risk and profitability associated with naturally occurring seasonal variability in fish attributes. Second, seafood markets can be extremely volatile due to both supply and demand variability. Producing a portfolio of products is one strategy for contending with market-related economic risks. However, because the development of markets for nontraditional and new products requires time and investment, it is important to consider all factors that may affect decisions to produce alternative product forms—including the investment-inhibiting effects of regulated open-access management strategies and policy uncertainty. A portfolio approach provides industry and resource managers with a potentially valuable framework to evaluate complex natural resource issues and develop management strategies best suited to balancing multiple objectives.

This analysis was conducted with data corresponding to a period during which the fishery was being developed. As such, the costs may not be representative of current production efficiencies. The alternative products included some that were not produced from Pacific whiting but were considered to have potential given markets from similar and competing whitefish species. A changing global whitefish market would likely change the specific product forms included if the analysis were repeated. Most importantly, from an economic perspective, availability of more seasonal price and cost data series would allow for the calculation of intra- and inter-season (monthly and annual) covariance matrices. Aside from economic parameters, the status of the stock (size and composition) would also affect results. A recent decline in total harvest quotas could, for example, allow the model to select optimal portfolio levels without the influence of demand constraints. In general, this study provides an illustration of how portfolio analysis can be applied to fisheries and fish processing, and how the results are important for different industry segments.

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