AN ABSTRACT OF THE THESIS OF

Chris R. Tuininga for the degree of Master of Science in Agricultural and Resource Economics presented on December 19, 1997. Title: Contending with Risk in the Seafood Processing Industry: A Bioeconomic Portfolio Analysis of the Pacific Whiting Fishery.

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Abstract Approved: ______________________

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Since harvest levels of many of the world's fisheries are not likely to increase in the foreseeable future, resource managers and seafood processors need to develop improved strategies to maximize the utilization and benefits of current catches. In addition to increasing utilization and benefits, seafood processors are subject to the risks associated with variation in harvest levels and market prices of seafood product forms. While bioeconomic models have been developed to attempt to determine more efficient processing and management strategies, little research has attempted to address the issue of processor risk. Portfolio theory is one methodology that can be used to analyze the trade-off between the benefits and risks of producing alternative proportions of product forms. Furthermore, improved utilization of catches can be incorporated through the integration of portfolio and bioeconomic models.

Pacific whiting (*Merluccius productus*) is used as a case study in which to show the potential benefits of portfolio diversification while attempting to maximize the utilization and benefits of the fishery. Whiting is one of the most important fisheries along the Pacific Coast of the United States in terms of its ecological and commercial value. While the domestic fishery has only been in existence since the early 1990's, a significant number of ecological, biological, management, and market development studies have been conducted. The objective of this research is to use the information provided by these studies in the development of a bioeconomic portfolio model in order to provide insight into more efficient processing and management strategies.

The study results indicate that the industry may be able to reduce its exposure to risk while sacrificing relatively little in benefits by changing its production mix. However, the majority of efficient portfolios were dominated by relatively few product forms, indicating that broad diversification is not essential. The bioeconomic portfolio model also provided information concerning the order in which to process product forms during the harvesting season. Lastly, processing late, rather than early, in the harvest season was found to increase the overall benefits.

Contending with Risk in the Seafood Processing Industry: A Bioeconomic Portfolio Analysis of the Pacific Whiting Fishery

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed December 19, 1997
Commencement June 1998

Master of Science thesis of Chris R. Tuininga presented on December 19, 1997

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ACKNOWLEDGEMENTS

Financial support for this research was provided by Oregon Sea Grant, the Coastal Oregon Marine Experiment Station, and the Department of Agricultural and Resource Economics, Oregon State University. Sincere appreciation is extended to Dr. Gil Sylvia, major professor, and committee members Drs. Steve Buccola, Dick Johnston, and Kermit Cromack, all of whom provided their expertise and support in completing this study.

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CHAPTER 1

INTRODUCTION

1.1 Seafood Processing

The successful growth of the United States seafood industry depends on its ability to evolve and compete within national and international seafood markets. Since US harvests are not likely to increase in the near future except through more efficient public management of the stocks, growth in economic benefits must result from improved harvesting and processing strategies. A subset of these strategies must address problems associated with species variability. This variability includes seasonal and yearly differences in stock biomass; however, it also includes variation in specific characteristics of the stock including the size of individual fish and their "intrinsic" quality attributes. Intrinsic quality consists of the physiological and chemical characteristics of fish that impact physical, sensory, and orgonoloptich characteristics including texture, color, smell, and taste (Love, 1988). Many of these characteristics are associated with the proximate composition of the fish which includes the relative proportions of moisture, protein, fat, and ash content in the flesh (Nelson et al., 1985). Not only does proximate composition vary by species but it also fluctuates throughout the year, particularly in relationship to periods of feeding, migration, and spawning. This issue raises important questions about the optimal timing and location of harvesting and processing.

The production of a larger variety of product forms is one strategy to increase economic opportunities and effectively minimize some of the risk inherent in the processing sector. It is also a strategy which can take advantage of normal and seasonal variability in the intrinsic characteristics of seafood. A more stable processing industry can indirectly reduce the risk in the fishing sector and help sustain the development of the fishery. In producing a more diverse portfolio of products, processors can accomplish two objectives. First, they can maximize profits by having a wider variety of production alternatives from which to use the intrinsic characteristics of the raw product. In effect, processors are positioned to change product forms when the raw product does not meet required characteristics. For instance, if it is not possible to produce individual quick frozen (IQF) fillets as a result of black spotting caused by myxosporidea parasites (Sylvia and Gaines, 1992) in a number of species of good fish, developing production capabilities for breaded fillets might prove to be a more profitable alternative than, for example, a surimi or other minced product. Another example would be the possibility of increasing profits of some offshore processors by adding production of fish meal. This would result from the use of waste products from processing rather than dumping carcasses overboard.

A second reason for producing a portfolio of products is to decrease the amount of risk experienced by processing companies due to the volatility of seafood markets. The production of product forms that can be readily substituted for products from other species can provide stability to the industry if the prices for one or two of these products should significantly decrease. Since developing markets for new products takes time and incurs considerable expense, it is important to address product diversity early in the development of a fishery. The Pacific whiting (*Merluccius productus*) fishery is an example of an industry that could potentially benefit from increased diversification.

1.2 The Pacific Whiting Fishery

The Pacific whiting fishery accounts for approximately 74 percent of the total groundfish harvest off the West Coast of the United States (excluding Alaska)(PFMC, 1993). More importantly, it is the second largest harvest of any marine species in the US; only catches of Alaskan pollock, *Theragra chalcograma*, are greater. Using new estimation techniques, the Pacific whiting biomass was estimated to total 2.56 million mt in 1992 which was more than double the stock and potential harvests estimated in 1989 (Dorn et al., 1993). Given the new biomass estimate, whiting has the potential for an average annual harvest ranging from 250,000 - 500,000 mt. Whiting make annual feeding and spawning migrations similar to, but more expansive than, the migrations of cod and pollock. Pacific whiting spawn from December through March over the continental slope off Baja California. From April until August they migrate north to feeding grounds off Oregon, Washington, and southern British Columbia. During this feeding migration they become spatially distributed as the older and larger fish tend to swim further west and north. Since female whiting grow larger than their male counterparts, there also tends to be a higher proportion of females in the more northerly distribution (Stauffer, 1985). By September, Pacific whiting begin their spawning migration back to Baja California. Whiting begin recruitment into the fishery at age two and grow to approximately 40 cm. and 0.4 kg. upon maturity (around age four). They can live up to 15 years. The Pacific whiting stock is also noted for large variation in biomass as a result of a seemingly stochastic pattern of varying strong and weak year classes (PFMC, 1993).

The domestic Pacific whiting fishery is currently in its infancy. Until the passage of the Magnuson Fisheries and Conservation Act in 1976, whiting was regarded by US fishermen as a trash fish. Most of what was caught was incidental and either discarded or sent to reduction plants for processing into fish meal. However, vessels from the Soviet Union had been catching whiting off the West Coast since 1966 and processing it at sea into headed and gutted product (H&G) and fillet blocks. The implementation of the Magnuson Act which extended the US jurisdiction of coastal waters to 200 miles effectively restricted foreign access. This initially resulted in the creation of joint venture operations between US fishermen and foreign at-sea processing vessels from the Soviet Union, Japan, and Poland. Since 1991 joint ventures were dissolved and domestic firms have undertaken all whiting processing. Currently over 70 percent of Pacific whiting is processed into surimi for sale in domestic and Asian markets. The remaining 30 percent is processed into H&G, fillets, and meal.

Currently the Pacific Fisheries Management Council (PFMC) and the Canadian Department of Fisheries and Oceans are responsible for the management of the fishery. In 1993 the US Pacific whiting allocation totaled 70 percent of the acceptable biological catch (ABC) and 128,106 mt was harvested domestically. Another 53,328 mt was caught by Canadian fishermen in 1993 (Dorn, 1994). Figure 1.1 depicts the total US harvest processed domestically for 1983-95 and the portion landed in Oregon (Radtke, 1995;

Lukas and Carter, 1994; Carter, 1995). Processing of Pacific whiting in the United States occurs in two sectors, shore-based plants and off-shore motherships and factory trawlers. The PFMC specifies an allocation of the total allowable catch (TAC) to be processed by on-shore and off-shore processors. From 1992-94 this allocation was 30 percent of the TAC for shore-based plants and 70 percent for at-sea processors. The harvest begins April 15th (the opening date) and ends when the TAC has been reached, most recently

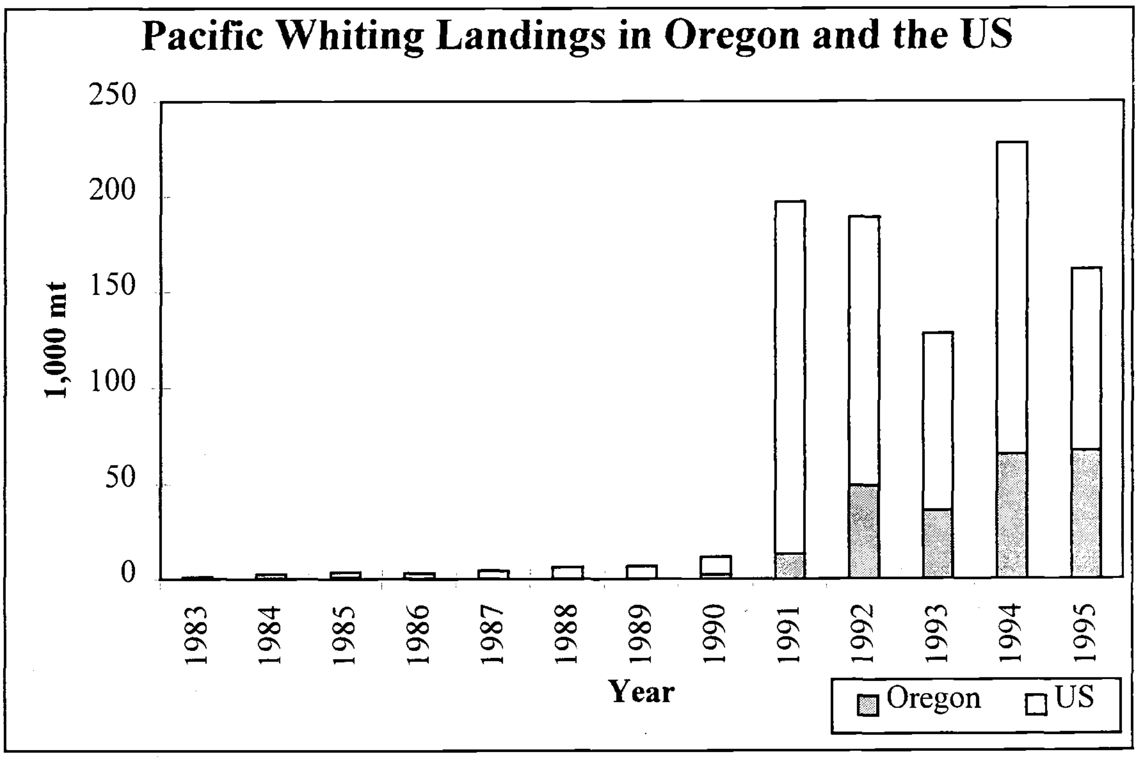


Figure 1.1 Annual Domestic Landings of Pacific Whiting

around mid June. Shoreside plants processed 38,200 mt of Pacific whiting in 1993 and generated more than $36 million in income (Radtke, 1993); shoreside processing in 1994 totaled 73,000 mt. The largest quantities of product are processed at plants in Newport, Oregon followed by Astoria, Oregon, Crescent City, California and Ilwaco, Washington. Figure 1.2 shows the quantities of whiting processed by port in Oregon (Lukas and Carter, 1994; Carter, 1995). Processors in Newport and Astoria have processed over 97 percent of whiting landed in Oregon over the last seven years.

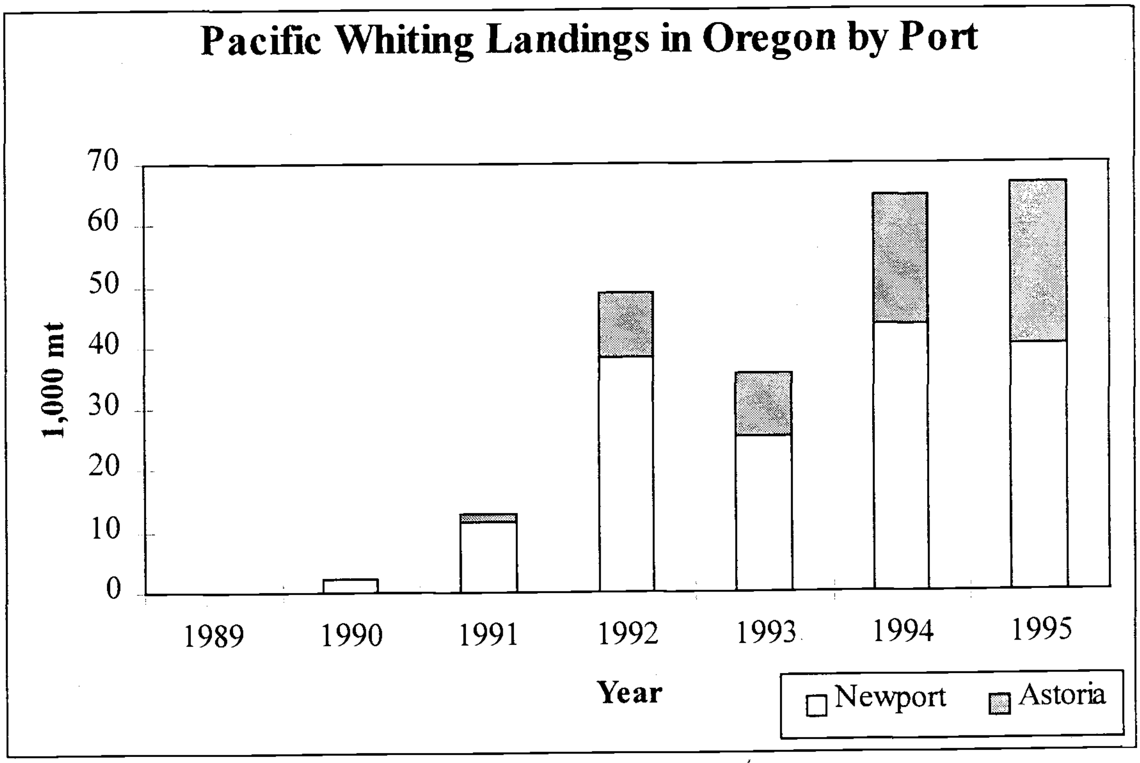


Figure 1.2 Annual Landings of Pacific Whiting in Oregon by Port

1.3 Pacific Whiting Processing

Variability in the intrinsic qualities of Pacific whiting final product forms is the result of rapid decomposition due to a characteristically soft and delicate flesh, protease enzymes, and myxosporidea parasites that make product handling and storage techniques extremely important (Sylvia and Gaines, 1992). Preserving the quality of the fish, therefore, necessitates processing the raw product within three to twenty hours after harvesting. Rapid processing of large quantities of fish requires methods of mass production which are capital intensive. Intrinsic quality and proximate composition of whiting also vary depending on the season, location of landings, and environmental conditions. Temporal variation in proximate composition of other species such as cod, pollock, and rock sole is similar to the variability which characterizes whiting (Bernatt-Byrne, 1991). Most notably, moisture content increases and protein content decreases through the spawning season. During the post spawning period these trends are reversed. Moisture content is the most critical measure of proximate composition and can significantly influence production possibilities and prices of end products (Sylvia, 1995). Therefore, raw product prices will ultimately be partially determined by the intrinsic characteristics and proximate composition of the catch as quality testing methods are improved. Eventually, quick testing methods such as those utilized in the meat industry may enable seafood buyers to evaluate incoming products objectively and set prices accordingly (Bernatt-Byrne, 1991). The ability to determine the intrinsic quality of the landings may also lead to the development of production standards and harvest management strategies.

Product forms such as fillets, surimi, blocks, steaks, whole, H&G, minced, meal, and breaded products appear to be viable end products that may be processed from Pacific whiting. However, the majority of processors presently produce only surimi, meal, and relatively small quantities of H&G and fillet product. Interviews with processors indicate a strong interest in producing alternative product forms, but also concern about risk in investment and biological and market uncertainties (Tuininga, 1995). The industry's present reliance on one product form makes it extremely sensitive to market fluctuations including the supply of substitutable products from species such as Alaskan pollock (Jensen, 1992). While also important to produce seafood products using various species so as to eliminate dependency on any one stock, the production of a variety of product forms from a single species may also be important in attempting to maximize both utility and revenue from harvests.

In addition to Pacific whiting processors being dependent on surimi as its primary product form, the risk of the industry is compounded by high volatility of surimi prices (Urner Barry, 1989-95). For example, in January 1991 the price of surimi imports to Japan was approximately $2.20 per kg. In December of the same year the price more than doubled to nearly $5.50 per kg. The price fell from this peak and by January 1993 was again at $2.20 per kg (PFMC, 1993). This price variability contributes to the uncertainty in the production decisions made by processors regarding quantity, grade, and market development. Diversification of product forms could be one strategy to reduce this two-fold risk.

1.4 Structure of the Research

This thesis attempts to determine whether increased profits and/or a reduction in risk can be achieved through the diversification of product forms by seafood processors. Portfolio analysis is utilized to establish the trade-off between risk and expected return for various combinations of alternative seafood product forms. Portfolio theory and the concept of diversification as a means to reduce the risk of investments was developed by Harry Markowitz in the early 1950's (1952, 1991). It is based on a decision model which maximizes expected utility as a function of expected return and degree of risk. Simple diversification occurs by merely increasing the number of securities in a portfolio, that is, not putting all ones "eggs in one basket". While this attempt at diversification may decrease risk, it may also reduce the rate of return because it does not incorporate the covariance between assets. Markowitz diversification, however, reduces risk without sacrificing the expected rate of return. It achieves this through a model which minimizes the covariances between securities, minimizing risk given an expected rate of return. This thesis entails applying this theory to the seafood processing industry.

The second chapter, titled "Application of Portfolio Analysis to Seafood Processing", introduces portfolio analysis as a theoretical approach to provide insight into the trade-off between expected return and risk. The chapter begins by describing the evolution of portfolio theory from its origins, primarily in the finance literature, to its applications in farm management. The discussion then shifts to the application of portfolio analysis to the food processing sector and develops a theoretical framework from which applied analysis can be accomplished. Finally, methods are proposed for constructing portfolios when incomplete information and undeveloped markets exist.

Chapter 3, entitled "Diversification of Pacific Whiting Product Forms", applies the theory and methods developed in the second chapter to the seafood processing industry. The Pacific whiting fishery, still in the early stages of development, provides a unique case study in which to show the potential gains of product form diversification from a single species. In this static representation of the fishery and processing alternatives, product forms are treated as if they were commodities in the asset markets. This research provides a look into the long run profitability and risk associated with individual product forms and various combinations which could be constructed to potentially provide a single firm, as well as the entire industry, with more efficient production strategies.

The fourth chapter, titled "Integration of Portfolio Analysis with a Bioeconomic Model of the Pacific Whiting Fishery", combines the portfolio model developed in the preceding chapter with a multi-year seasonal bioeconomic model of the fishery in order to determine optimal portfolios of product forms. This dynamic model also incorporates yearly variation in stock recruitment as well as seasonal variation in the size and intrinsic qualities of the fish. In addition, the bioeconomic portfolio model helps provide insight into what inter- and intraseasonal harvest levels might be if firms operated as profit maximizers.

Chapter 5 summarizes the findings and implications of the first four chapters and proposes potential areas for future research and analysis.

CHAPTER 2

APPLICATION OF PORTFOLIO ANALYSIS TO SEAFOOD PROCESSING

2.1 Introduction

Investors are often concerned with eliminating uncertainty in the expected returns from a portfolio of assets. In 1952 Harry Markowitz (1952) provided a means to quantitatively compare an infinite number of potential portfolios and select those which have minimum risk given an expected level of return. A large body of literature on portfolio analysis has followed Markowitz's seminal article, most of which is related to the securities markets for which the theory was originally developed. However, due to the general nature of this theory, his work has been extended to numerous fields. This chapter explains how portfolio theory and methodology can be extended to include food processing strategies. First, Markowitz's original theory and methodology are described. Following this section is a discussion of some of the alternative portfolio model specifications and their potential applications. Then a brief overview of utility theory and its application to portfolio analysis provides explanation of portfolio selection by individuals or firms. Next, some of the extensions of portfolio theory outside of the finance literature are reviewed. Finally, a methodology is proposed for applying portfolio analysis to the production of alternative product forms by seafood processors. This methodology includes alternative model specifications that could be used in various fisheries and processing industries.

2.2 Markowitz Diversification

In order to demonstrate why portfolio diversification is observed in the financial world, Markowitz (1952) had to disprove the hypothesis that investors seek solely to maximize returns. For if maximizing returns was the only objective, there would be no rationale for diversification. In this case individuals would be indifferent to risk and choose the investment with the highest return. Markowitz argued that due to uncertainty in future returns, investors are concerned with the expected return, *E*, of a given asset or portfolio of assets. The uncertainty inherent in *E* provides an element of risk which can be measured in terms of the past variance, *V*, of *E*. Since *V* is an economic "bad" in that risk averse investors require a higher return or risk premium for investing in securities with greater variance, a trade-off between *E* and *V* results. The Markowitz or full-covariance model (Markowitz, 1952, 1987, 1991; Alexander and Francis, 1986; Elton and Gruber, 1984) was developed to generate *E-V* combinations and allow investors to determine their optimal portfolio given their *E-V* preferences.

The standard equation used in financial markets to determine the observed rate of return r for security i at time t as a percentage is given by: $r_{i,t} = \left(v_{i,t} - v_{i,t-1}\right) / v_{i,t-1}$ where v is equal to value and $t = (1,\ldots,T)$. The expected return for an individual security when its observed returns are equally likely is their mean, computed as: $\bar{r}_i = \frac{1}{T}\sum_{t=1}^{T} r_{i,t}$. Alternatively, if the asset's observed returns are not equally likely or follow some probability distribution, expected return can be calculated as: $\bar{r}_i = \sum_{t=1}^{T} r_{i,t}\, p\left(r_{i,t}\right)$ where

p is the probability that $r_{i,t}$ will occur. Given n assets in a portfolio, the sum of the proportions invested in each asset, x, must sum to one, such that

$$\sum_{i=1}^{n} x_i = 1 \quad . \tag{2.1}$$

The expected rate of return for the portfolio, E, is therefore the weighted sum of the expected returns of the individual securities where

$$E = \sum_{i=1}^{n} x_i \bar{r}_i \quad . \tag{2.2}$$

In utilizing the Markowitz model, the variance-covariance matrix of past returns between all assets to be considered for portfolio selection must be estimated. The variance of the returns of the individual assets can be derived through the standard equation $\sigma_i^2 = \sum_{t=1}^{T} \left(r_{i,t} - e(r_i)\right)^2 p\left(r_{i,t}\right)$ where e is the expected value, or more simply

$$\sigma_i^2 = e\left(\left(r_i - \bar{r}_i\right)^2\right) \quad . \tag{2.3}$$

The covariance of returns between securities i and j is calculated as $\sigma_{i,j} = e\left(\left(r_i - \bar{r}_i\right)\left(r_j - \bar{r}_j\right)\right)$. Equation (2.3) can also be used to determine the variance of portfolio P such that

$$\sigma_P^2 = V = e\left(\left(r_P - E\right)^2\right) \text{ where } r_P = \sum_{i=1}^{n} x_i r_i \; . \tag{2.4}$$

If, for simplicity, only two securities were used for portfolio selection, the variance of the portfolio's returns could be derived by substituting equation (2.2) into equation (2.4) such that

$$\sigma_P^2 = e\left(\left(x_1 r_1 + x_2 r_2 - x_1\bar{r}_1 - x_2\bar{r}_2\right)^2\right)$$

$$\sigma_P^2 = e\left(x_1^2\left(r_1 - \bar{r}_1\right)^2 + x_2^2\left(r_2 - \bar{r}_2\right)^2 + 2x_1 x_2\left(r_1 - \bar{r}_1\right)\left(r_2 - \bar{r}_2\right)\right)$$

$$\sigma_P^2 = x_1^2\sigma_1^2 + x_2^2\sigma_2^2 + 2\left(x_1 x_2 \sigma_{1,2}\right) .$$

This can be generalized for n securities by

$$\sigma_P^2 = V = \sum_{i=1}^{n}\sum_{j=1}^{n} x_i x_j \sigma_{i,j} . \tag{2.5}$$

Using vector optimization, this final equation for portfolio variance (2.5) can be minimized in a non-linear programming model subject to a specified expected rate of return. Actual portfolio risk is defined as the standard deviation (i.e., σ_P). Using matrix notation, equations (2.1), (2.2), and (2.5) can be written more concisely. The fraction invested in each asset is given by the **X** vector which is of nx1 dimensions. **R** designates the vector of expected returns (nx1), and **L** is a (nx1) vector consisting of 1's. **C** is the variance-covariance matrix of the assets (nxn)

$$\mathbf{X} = \begin{bmatrix} x_1 \\ x_2 \\ x_i \\ \vdots \\ x_n \end{bmatrix}, \quad \mathbf{R} = \begin{bmatrix} \bar{r}_1 \\ \bar{r}_2 \\ \bar{r}_i \\ \vdots \\ \bar{r}_n \end{bmatrix}, \quad \mathbf{L} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}, \quad \mathbf{C} = \begin{bmatrix} \sigma_{1,1} & \sigma_{1,2} & \sigma_{1,j} & \cdots & \sigma_{1,n} \\ \sigma_{2,1} & \sigma_{2,2} & \sigma_{2,j} & \cdots & \sigma_{2,n} \\ \sigma_{i,1} & \sigma_{i,2} & \sigma_{i,j} & \cdots & \sigma_{i,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \sigma_{n,1} & \sigma_{n,2} & \sigma_{n,j} & \cdots & \sigma_{n,n} \end{bmatrix} .$$

Assuming that assets cannot be sold short, an additional stipulation that x_i is non-negative may be used. The basic equations used in the full-covariance portfolio model are therefore:

$$\text{Minimize:} \quad V = \mathbf{X'CX} \tag{2.6}$$

$$\text{Subject to:} \quad E = \mathbf{X'R} \tag{2.7}$$

$$\mathbf{X'L} = 1 \tag{2.8}$$

$$x_i \geq 0$$

Covariances between assets play an important role in decreasing portfolio return variability. Since V is a weighted average of the variances and covariances of the included securities, V declines as the correlation between assets decreases. Hence, a security with a low return might be an attractive investment if its returns are poorly correlated with the returns of other assets. A minimum variance boundary can be constructed by solving equations (2.6) through (2.8) over the available range of E of the securities being considered. Efficient portfolios are those which lie on the concave portion of the minimum variance frontier. These portfolios are efficient because they have the least amount of risk for a given expected rate of return and they have the highest expected return for a given level of risk. Figure 2.1 illustrates a minimum variance boundary (abc) and efficient frontier (bc) of portfolios constructed from nine individual securities.

Portfolio frontier construction using E-V analysis generally uses parameter estimates derived from previously observed returns. This procedure assumes that the estimates are an adequate representation from which to predict the future expected returns and return variability of alternative portfolios. Generally, parameter estimates are based on observed monthly returns over a five year period. This is done to preclude computing estimates based on old and perhaps no longer relevant covariation among assets. However, if the decision maker believes that the parameter estimates do not reflect the expected future returns of an asset or their variability, the estimates of expected return and variance of return may be adjusted accordingly.

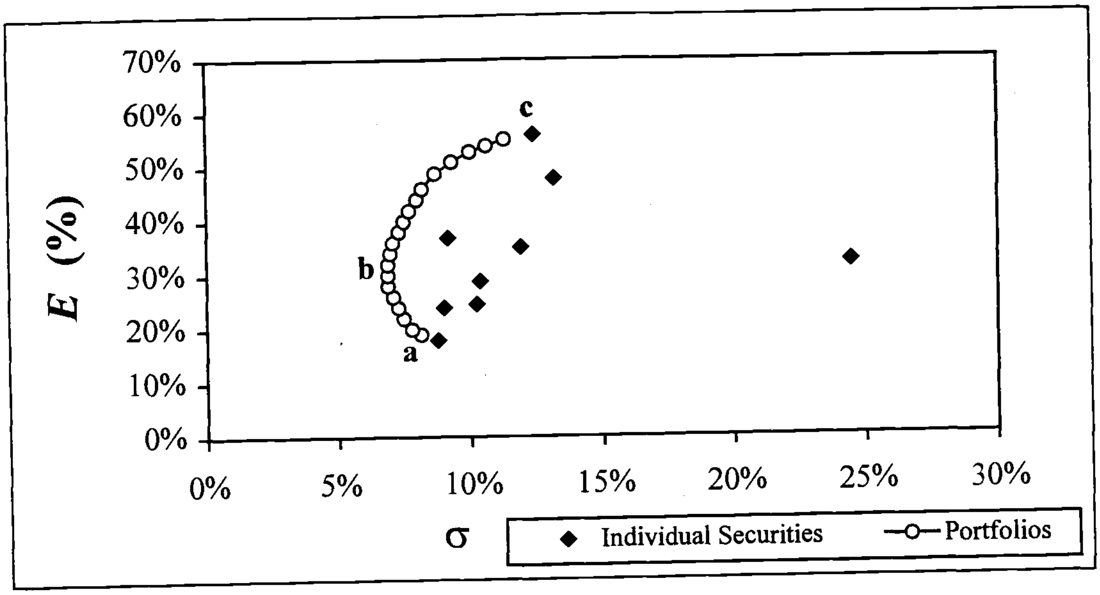


Figure 2.1 Minimum Variance and Efficient Portfolio Frontiers

2.3 Alternative Portfolio Models

Numerous methods have been derived from Markowitz's original work to estimate the risk of individual securities and construct efficient portfolios (Alexander and Francis, 1986). Some models approximate the full-covariance model through simplification by reducing the number of estimated parameters required to solve for minimum variance portfolios. Models have also been constructed to incorporate various structures and assumptions about asset markets in addition to correcting for statistical and programming problems. The most commonly used portfolio models having alternative specifications are the Tobin model, the market or single-index model developed by Sharpe, and the Black model.

The Tobin model (Tobin, 1958; Elton and Gruber, 1984) relaxes the model specifications of the Markowitz model by including securities with no variance or risk. This method allows for the incorporation of a risk-free asset, such as a 30-year treasury bond, as an additional security to be used in conjunction with minimum variance portfolios. However, the risk-free security is not used directly in solving for the minimum variance portfolios or frontier. Rather, the risk-free asset is considered as an alternative from the portfolio choices. The risk-free security is combined in different proportions with the optimal or market portfolio through borrowing or lending in order to achieve the desired amount of investor risk. The market portfolio is at the point of tangency between the minimum variance portfolio frontier and the line intersecting the risk free asset, r_f, as illustrated in Figure 2.2. This line, which represents the efficient portfolio frontier, is called the capital market line. An investor having a risk preference less than that associated with the market portfolio will allocate a portion of their investments to the market portfolio and the remainder to the risk free alternative. An investor having a risk preference greater than the market portfolio will borrow at the risk free rate and invest the additional amount in the market portfolio, achieving risk levels greater than the market portfolio. The idea that portfolio choice is independent of an investor's risk preference is known as the Tobin separation theorem (Tobin, 1958; Markowitz, 1987).

The single-index or market model (Sharpe, 1963, 1970; Alexander and Francis, 1986) is a simplified version of Markowitz's full-covariance model. This simplification results from a restriction that there is a linear relationship between the return of a specific security and the return of a market index. This method significantly reduces the number of parameters that must be estimated when a large number of securities are being considered for portfolio selection.

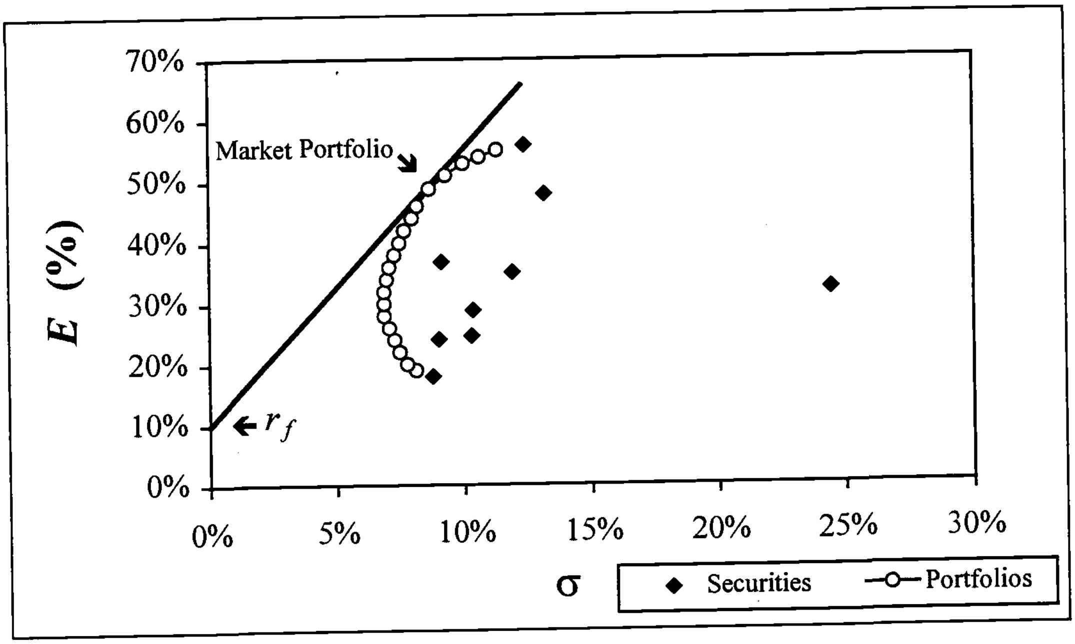


Figure 2.2 The Tobin Model

In the single-index model, asset betas replace the variance-covariance matrix used in the Markowitz model. Asset betas are a measure of asset return volatility relative to the market and are the slope coefficients estimated through OLS regressions. Monthly returns for each security are regressed in a simple bivariate model against a constructed market index. A security with an asset beta of one would move in step with the market index and thus exhibit the same volatility. An asset with a beta of two would experience twice the volatility of returns relative to the market index. While less common, a security with a negative beta would be negatively correlated with the market portfolio and thus be an important asset in reducing portfolio risk. The simple bivariate regression equation used for beta, β, estimation is defined as

$$r_{i,t} = \alpha_i + \beta_i r_{m,t} + \varepsilon_{i,t} \quad . \tag{2.9}$$

where ε is a random-error term such that $e(\varepsilon_{i,t}) = 0$ and $r_{m,t}$ is the market index rate of return. The intercept term, α, can be interpreted as the return on the individual security when the market index is earning zero return. The expected return and beta of the portfolio are calculated, respectively, as

$$E = \sum_{i=1}^{n} x_i\left(\alpha_i + \beta_i \bar{r}_m\right) \quad . \tag{2.10}$$

$$\beta_P = \sum_{i=1}^{n} x_i \beta_i \quad . \tag{2.11}$$

The single-index model uses the parameters estimated in the regressions to calculate the variances and covariances of expected returns for all securities. By inserting the right-hand side (RHS) of equation (2.9) into the standard equations to estimate variance and covariance, the following equations are derived:

$$\sigma_i^2 = \left(\beta_i \sigma_m\right)^2 + \sigma_{\varepsilon_i}^2 \tag{2.12}$$

$$\sigma_{i,j} = \beta_i \beta_j \sigma_m^2 \quad . \tag{2.13}$$

Equation (2.12) calculates asset variance and assumes that the error term is not correlated with the return on the market, such that $cov(r_{m,t}, \varepsilon_{i,t}) = 0$. The first RHS term in (2.12) measures the stock's market risk which is nondiversifiable (or systematic). The second RHS term indicates the amount of stock specific risk that can be reduced through diversification, called unsystematic or diversifiable risk. In a well diversified portfolio this latter term becomes insignificant. Covariance between securities, equation (2.13), assumes that securities are only related through their similar variation with the market and therefore $cov(\varepsilon_{i,t}, \varepsilon_{j,t}) = 0$ when $i \neq j$. The minimum variance frontier, using the single-index model, can be estimated through the following system of equations:

$$\text{Minimize: } \quad V = \left(\sum_{i=1}^{n} x_i \beta_i \right)^2 \sigma_m^2 + \sum_{i=1}^{n} x_i^2 \sigma_{\varepsilon_i}^2 \qquad (2.14)$$

$$\text{Subject to: } \quad E = \sum_{i=1}^{n} x_i (\alpha_i + \beta_i \bar{r}_m)$$

$$\mathbf{X'L} = 1$$

$$x_i \geq 0$$

The Black model (Black, 1972; Alexander and Francis, 1986) is an alternative asset market specification that can be used with either the full-covariance or single-index model. The Black model relaxes the constraint that the proportions invested in each security must be positive and thus would allow for selling securities short. This methodology would derive a minimum variance portfolio frontier in the shape of a parabola with neither an upper or lower bound.

Other alternative model specifications include the use of upper bounds on the proportion invested in any one asset and the use of multiple-index models. The multiple-index model (Cohen and Pogue, 1967; Elton and Gruber, 1984) is a deviation on the single-index model in that it incorporates an additional index in the regression equation. Often an industry related index is used in addition to an overall market index in order to capture some of the additional covariance relationships among assets.

2.4 Utility Theory

In order to establish criteria to define optimal portfolio selection by individuals based on their *E-V* preferences, some basic assumptions concerning utility theory are required. These assumptions are made in addition to the axioms developed by von Neumann and Morgenstern (1944) which attempt to explain economic behavior in terms of expected utility rather than expected value. First, individuals are assumed to have unsatiable wants and thus desire more wealth to less. Since utility, U, is a function of wealth, W, nonsatiation requires that marginal utility be positive where $U'(W)>0$. Furthermore, the wealth of investors is a function of the expected return of the assets they hold in their portfolios, where $W=W^*(1+E)$ and W^* is some level of initial wealth. Hence, portfolio choice ultimately influences an individuals expected utility level. Secondly, individuals are assumed to be risk averse in that they will not enter into a fair bet. This implies that given the choice between a specified return and an equal expected return with a known probability distribution, the individual will choose the former. This assumption requires that the functional form of the utility equation be concave in that $U''(W)<0$. Given the assumption that individuals attempt to minimize risk, a higher rate of return or risk premium is required for increased return volatility. Lastly, individuals are assumed to have decreasing absolute risk aversion meaning that those with greater initial wealth are more likely to take larger risks. Absolute risk aversion depends on the exact shape of the individual's utility function and can be determined using Pratt's (1964) risk aversion measure, $A(W)$, where $A(W) = -U''(W)/U'(W)$. If $A'(W)<0$ the investor's utility function exhibits decreasing absolute risk aversion.

The two most commonly used functional forms for describing utility functions are quadratic and logarithmic, however exponential and power functions have also been utilized (Alexander and Francis, 1986). A logarithmic utility function of the form $U(W)=ln(W)$ meets the assumptions used in *E-V* analysis in that marginal utility is positive and diminishing as wealth increases. The logarithmic form also provides for decreasing absolute risk aversion. If the rates of returns are assumed to be normally distributed then the logarithmic form allows for portfolio choice in terms of expected return and variance. However, the function must be bounded from above to eliminate the St. Petersburg phenomena from occurring (Nicholson, 1992). The St. Petersburg paradox shows that expected value theory can be illogical in certain game situations which have an infinite expected payoff, yet no individual would be willing to play for a finite sum.

Quadratic utility functions are often assumed in portfolio analysis because they provide results in which expected utility is precisely a function of the mean and variance of the portfolio return, even if the rates of return are not normally distributed (Elton and Gruber, 1984). This can be shown through Taylor series expansion. Quadratic utility functions take the general form $U = a + bW + cW^2$. However, there are numerous problems with this model specification. First, in order to achieve positive but decreasing marginal utility, the signs on the coefficients b and c must be specified where $b>0$ and $c<0$. This restriction on the functional form creates a problem in that it allows for negative marginal utility, which violates the assumption of nonsatiation. This problem can be alleviated though a constraint that terminal wealth beyond the function's maximum point, at $W=-b/2c$, is not feasible. Secondly, quadratic utility functions also result in increasing rather than decreasing absolute risk aversion.

Given the assumptions concerning an individual's utility curve, indifference or iso-utility curves can be constructed which show an investor's preferences in E-V space. Through Taylor's series expansion of an individual's expected utility function, it can be shown using partial derivatives that:

$$\frac{\partial e(U)}{\partial \overline{W}} = f'(\overline{W}) > 0 \tag{2.15}$$

$$\frac{\partial e(U)}{\partial \sigma_W} = \sigma_W f''(\overline{W}) < 0 \tag{2.16}$$

Equations (2.15) and (2.16) affirm the assumptions of nonsatiation and risk aversion, respectively. Hence, an investor's utility can be increased through greater expected wealth and/or a reduction in the volatility of expected wealth. These equations dictate that an individual will have convex indifference curves and therefore achieve higher utility by moving in a northwest direction among them. The optimum portfolio of an individual is determined by the point at which the highest obtainable indifference curve is tangent to the efficient portfolio frontier as illustrated in Figure 2.3.

2.5 Extensions of Portfolio Theory

The applicability of portfolio theory extends far beyond finance markets. In the agricultural economics literature, numerous models have been constructed to evaluate increased potential profits and/or the reduction of risk through crop diversification strategies. Other studies have focused on supplementing financial market securities with unconventional assets, such as agricultural futures contracts or investments in timber land, as a means to diversify. Recent work on dynamic portfolio models have analyzed the effects of diversification over time.

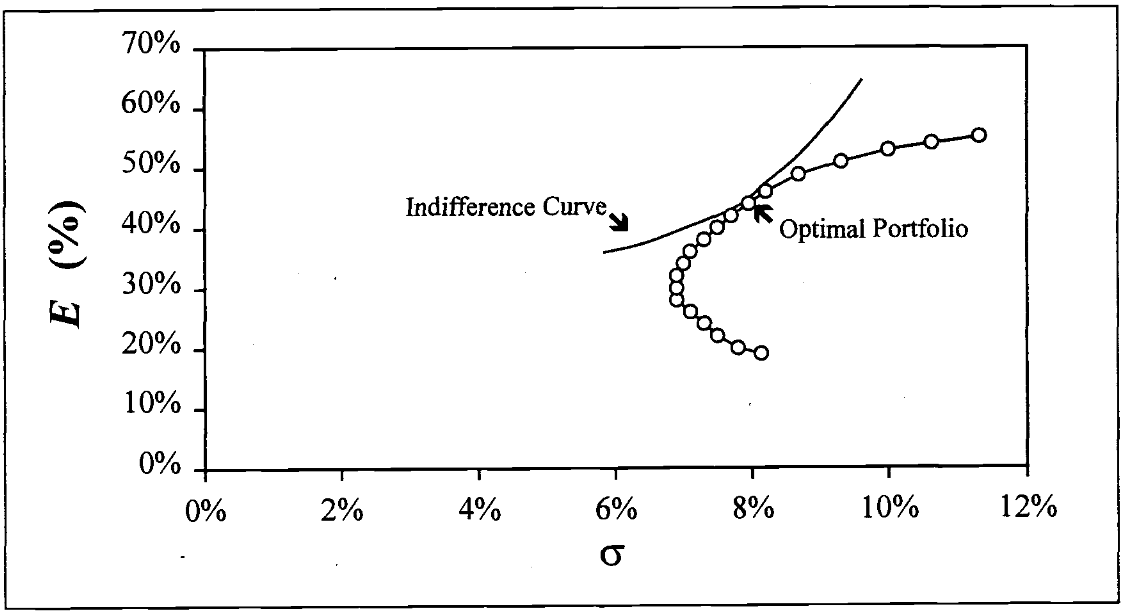


Figure 2.3 Optimal Portfolio Selection and the Markowitz Model

Diversification strategies in agricultural settings emerged at about the same time as Markowitz's *E-V* analysis for financial markets. Heady (1952) studied the results of alternative diversification strategies in which farmers produced two crops in different proportions in order to reduce risk and/or increase revenues rather than relying on income from just one crop. Heady used equations similar to those of the full-covariance model but utilized gross and net incomes per acre of the alternative crops rather than their expected returns. A review of the fundamental implications of portfolio analysis to farm planning and a request for further investigation in this area was provided by Stovall (1966).

Johnson (1967) provided theoretical analysis of the application of the Tobin model in agricultural portfolio construction. Tobin's separation theorem was utilized in two alternative scenarios in which the option of leasing additional land was available to farmers. Burt and Johnson (1967) incorporated portfolio analysis in a dynamic wheat production model to determine the *E-V* trade-off of alternative rotation strategies of growing wheat or letting the land go fallow.

Due to the limited computational resources required to solve the quadratic equation of the Markowitz model, Hazell (1971) developed a linear programming model to approximate the set of portfolios of the minimum variance frontier. Hazell and Scandizzo (1974) extended this method to include a linear programming model in which the expected price for a crop was a function of the quantity produced through a market equilibrium approach.

Portfolio analysis generally assumes that there are no transactions costs associated with constructing or revising a portfolio's makeup. This tends to overestimate the number of adjustments that would occur in managing a portfolio had these costs been incorporated. Robison and Brake (1979) modified portfolio equations to include transaction costs in agricultural applications of portfolio analysis.

In addition to the volatility in observed prices, farmers are subject to variability in costs due to environmental factors that affect output. However, unlike the price risk, farmers can affect a portion of the volatility associated with the yields of various crops through the use of fertilizers, pesticides, and crop rotation strategies. These factors have a significant impact on the proportion of land allocated to each crop in a farmer's portfolio (Feder, 1980). Lins, Gabriel, and Sonka (1981) used direct observations of economic behavior in order to determine the degree of absolute and relative risk aversion experienced by farmers. They found that farmers exhibit decreasing absolute risk aversion while the specification of risk-free assets, either farmland or time deposits, influenced the estimates of relative risk aversion.

Mills and Hoover (1982) use portfolio analysis for analyzing investments in financial assets, timber land, and agricultural crops. They found that due to the low correlation in expected returns of timber land with the other alternatives, timber can be an important risk reducing investment. Collins and Barry (1986) compare similar minimum variance frontiers constructed using the Markowitz and a single-index models in which twelve crops were used for portfolio selection. Diversification strategies for catfish farmers using a dynamic linear programming model were investigated by Hatch and Atwood (1988). In this study the variability in returns was a function of the survival rates for the fish at specific stages of growth: eggs, fry, fingerlings, and food fish. Utilization of agricultural futures contracts in investment diversification was explored by Fortenbery and Hauser (1990). Dynamic portfolio analysis and applications are discussed by

Krautkraemer et al. (1992) and a more formal presentation of risk and dynamic programming is provided by Alexander and Francis (1986).

2.6 Portfolio Analysis of Seafood Product Forms

Food processing firms generally have a variety of different product forms they can produce from a given primary input. These product forms differ in the amount and type of additional inputs necessary to produce them and vary in the amount of profit the products receive in the marketplace. To date, there have been no applications of portfolio theory to seafood production either for a single species or multiple species. In fact, there appear to be no applications of portfolio analysis in food processing. Given the framework of research on portfolio analysis performed on the production of agricultural crops and the similarities between agricultural crops and seafood product forms, this research builds on existing studies. However, there are some fundamental differences between primary and end-product diversification. This section considers some of these differences and attempts to provide a means to incorporate them into portfolio choice models.

2.6.1 Application Considerations

Portfolio selection models utilized in agricultural settings such as Heady (1952) and Collins and Barry (1986) provide a simple analysis of the potential gains available to farmers through diversification practices. The methods used in these studies are directly applicable to the food processing sector. However, some additional considerations on applying portfolio theory to end-product diversification are necessary. These considerations include the estimation of a firm's utility function, additional sources of risk encountered by a firm, and the existence and development of markets for the end products.

Unlike a farming situation where there is generally a single decision maker, production decisions by a firm are often the result of a consensus of a group of individuals. This could potentially violate the von Neumann and Morgenstern (1944) axioms of an individual's preferences under uncertainty. However, Sandmo (1971) argues that for most firms, either production decisions are made by one individual or the individuals making production decisions have similar preferences. Thus, estimation of a group's utility function can be derived by the same means as an individual's utility function.

The simplifying assumption that a processor's risk is solely a function of the variability in returns is in all likelihood unrealistic. A processor's production decisions for example, may be influenced by risk stemming from the variation in output as a result of variable product recovery rates. Variability in the availability of the primary input presents another source of risk to the processor (Jensson, 1988). Seafood processors, who rely on commercially harvested wild species, are dependent upon a relatively more uncertain source of raw product than other food processors. The productivity of a fishery, like an agricultural crop, is subject to environmental variation which affects natural growth and mortality rates. However, another source of variability in harvest results from the biological characteristics of the specific stock. Biological characteristics such as fecundity as well as variations in the size and age structure of the biomass may cause recruitment volatility and thus uncertainty in harvests (Cushing, 1973). In addition to the environmental and biological variation, availability of raw fish from exploited stocks to seafood processors ultimately depends on the fishery management regime (Rettig, 1995). These additional sources of risk can be modeled using sensitivity analysis or Monte Carlo simulation.

Finally, products can only be sold when there are individuals willing to purchase them. The establishment of markets for goods is often a lengthy and risky process. In many cases a significant amount of funds are spent on the initial research and development of the product. Based on the expected return of the good, additional capital expenditures, and sales projections, a firm makes the decision whether or not to begin production based on some criteria such as net present value and an estimation of market risk.

2.6.2 Methods

The selection of a portfolio model is a complex choice. The decision will likely be based on the specific characteristics of a processing firm, the number of, and correlation between, alternative product forms being considered for portfolio choice, and the preferences of the researcher. Regardless of the portfolio model chosen, some alternative modeling equations may be necessary when making the transition from primary to end-product portfolio decision models.

The full-covariance model incorporates all sources of covariation between product forms. However, the market model uses the assumption that product forms are related only through their linear relationship with a common market index. This simplifying assumption of the market model derives a minimum variance portfolio frontier which approximates that of the full-covariance model, but tends to overestimate the level of risk at any given expected return. Nevertheless, the single-index model may be useful when a large number of products are being considered for portfolio selection in order to decrease the number of parameters that must be estimated. Given the limited number of production choices available to seafood processors, computational constraints are not likely to be justified in using the single-index model.

A potential problem of the Markowitz model emerges when high collinearity in the data cause the variance-covariance matrix to be nearly singular, resulting in programming infeasibilities (Collins and Barry, 1986). Singular matrices are the result of the returns of one product form being a linear transformation of another. Although inspection and elimination of similar products could alleviate this problem, this solution may not be feasible since it is reasonable to assume that the returns of all products using the same primary raw material would be strongly correlated. The market model is not subject to this programming problem.

Utilization of the Tobin model requires the specification of a risk free alternative available to food processors; for example processors could lease out some of their plant capacity to other firms. Due to limitations in the supply of raw fish, most processors do not engage in such activities. Finally, while some processors engage in forward contracting of product to reduce their exposure to price risk, generally speaking a processor cannot sell a good which has not been produced, and therefore the Black model is irrelevant in applying portfolio analysis to food processing firms.

In estimating the variances and covariances among product forms, monthly returns to a food processor could be estimated using an equation such as

$$r_{i,\lambda} = \frac{P_{i,\lambda} - C_{i,\kappa}^{Raw\ Product} - C_{i,\kappa}^{Processing} - C_{i,\kappa \to \lambda}^{Storage}}{C_{i,\kappa}^{Raw\ Product} + C_{i,\kappa}^{Processing} + C_{i,\kappa \to \lambda}^{Storage}} \tag{2.17}$$

where i is the product form and κ and λ are the months harvested and sold, respectively. P is equal to the price received by processors and C equals the various costs of production. This equation would estimate net returns to capital, management and risk. Integration of supply equations into the portfolio model, such that the expected return of the product form is a function of the quantity produced, could also be modeled (Sandmo, 1971). In addition, demand equations could be used if the firm was not a price taker. Finally, a constraint that creates a lower bound on the production of individual product forms that are selected by the model may be required to prevent unrealistic production strategies. For example, a lower bound of five percent of total output into any individual product form would exclude negligible and impractical modeling decisions in which start-up costs would exceed revenues.

Numerous methods have been established to construct market indices when employing the market model (Aber, 1973). However, index choice is not critical as long it is related to the industry. In attempting to determine the reduction of risk obtainable by processors through the diversification of final product forms from a single primary product, an unweighted average of all viable product form returns could be used. This is the method used to calculate the Dow Jones Industrial Average (30 stocks) and the New York Stock Exchange Composite Index, and has been used as a means to establish indices in other portfolio analysis research (Collins and Barry, 1986; Cohen and Pogue, 1967; Sharpe, 1967). Weighted averages, in terms of the size of the firm, are also used for developing indices in financial markets; for example, the Standard and Poor 500.

2.6.3 Variability in Seafood Markets

Over the last decade there has been considerable transition in world seafood markets (Wessells and Wallström, 1993). Much of the change results from the establishment of exclusive economic zones to protect a nation's fisheries and from approaching, or in some cases exceeding, the maximum sustainable harvest levels of many of the world's fisheries (Weber, 1995). These factors complicate more traditional problems including changes in consumer preferences and availability of raw product-factors which make seafood markets inherently dynamic (Smith, 1975). This period of transition in seafood markets has translated into volatility in seafood product form prices. As shown in Figure 2.4 (Urner Barry, 1984-94; NMFS, 1995), variation in prices differs among product forms. Prices for fillets individually wrapped in cellophane, termed "cellopack fillets", are shown for cod and pollock. Whiting layerpack fillets are packaged such that individual layers of fillets are separated by cellophane. Fillet prices for cod and pollock (Figure 2.4.1) have standard deviations of 0.437 and 0.296, respectively. These fillet prices are relatively more volatile than prices of breaded products made from the same species (Figure 2.4.3), which have standard deviations of 0.373 for cod and 0.198 for pollock. Within product form classifications, prices among species show high correlation. Pollock and cod cellopack fillets have a correlation coefficient of 0.873

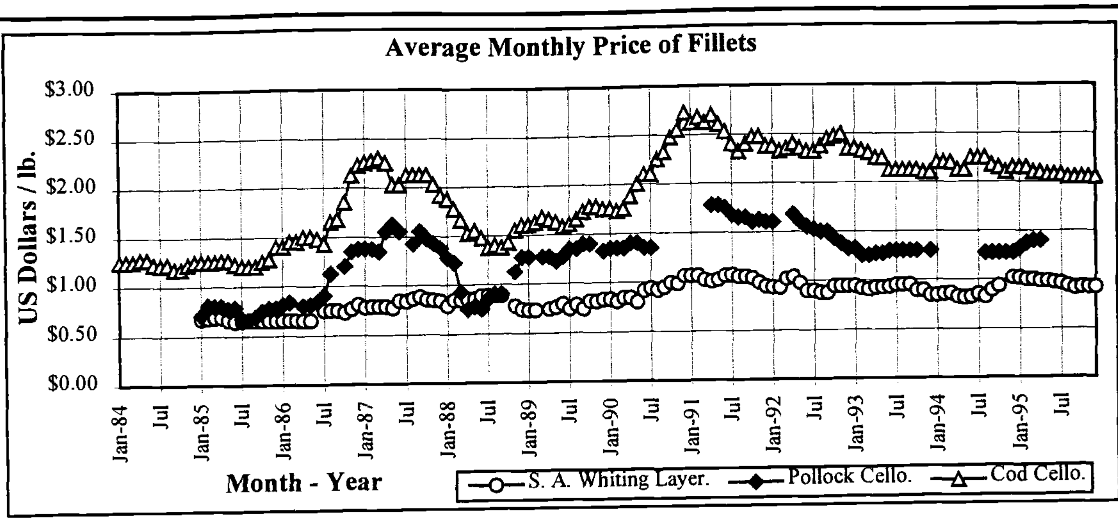


Figure 2.4.1

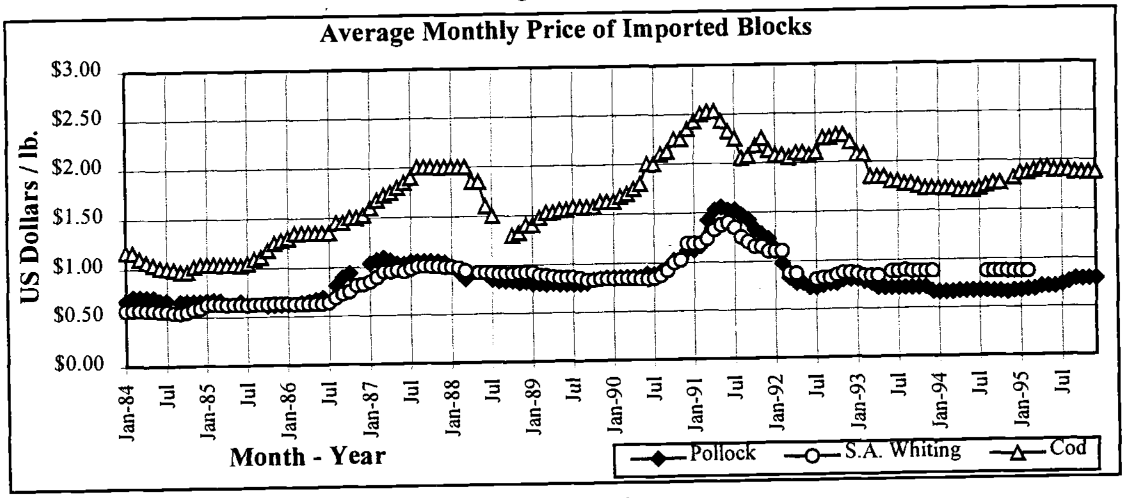


Figure 2.4.2

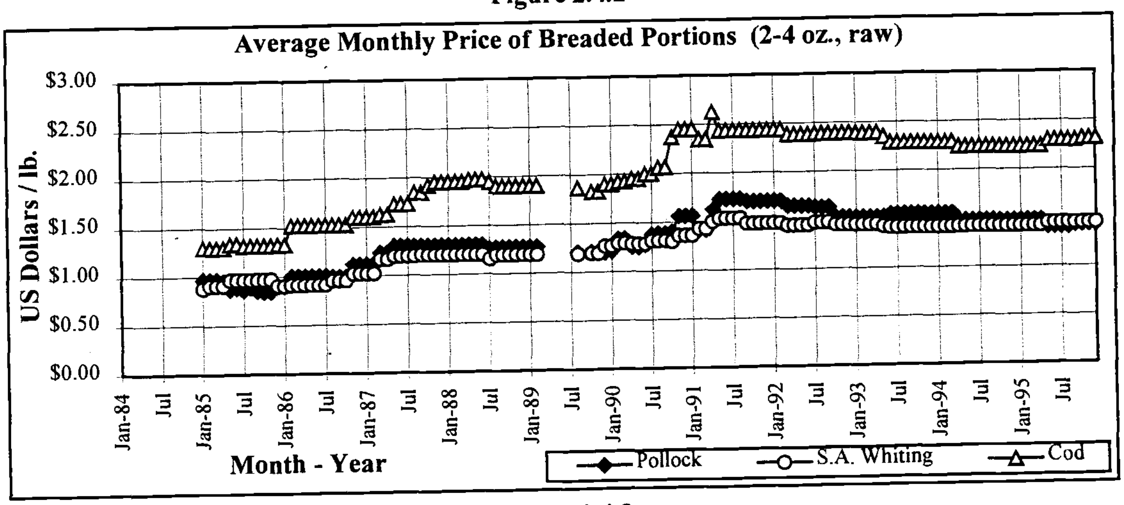


Figure 2.4.3

Figure 2.4 Seafood Product Form Prices, 1984-1995

while the coefficient between pollock and whiting blocks (Figure 2.4.2) is 0.869. Breaded product processed from pollock and whiting have a correlation coefficient of 0.952, showing an even higher degree of covariation. These high correlation coefficients indicate the substitutability among product forms of different species as noted by Shriver (1994).

Some other general trends are apparent among the three product forms, irrespective of species. Most notably, prices rose dramatically beginning in 1986, decreased in 1988, and again increased in early 1990. Due to the complexities of seafood markets, there are many factors affecting these price trends. However, world catches of Atlantic cod have been declining since 1982 (FAO, 1993), likely resulting in an increase in the price of cod products. Summarizing Shriver's (1994) analysis, a large portion of U.S. groundfish consumption in the late 1980's consisted of imported Atlantic cod products. The increase in cod product prices motivated domestic cod buyers to seek alternative sources of raw product. Partially in response to increasing prices, by 1987, significant domestic landings of Pacific cod and pollock helped to supplement the declining Atlantic cod imports. However, in 1989, further reductions in Atlantic cod harvest quotas in addition to attaining maximum harvest levels for Pacific cod and pollock resulted in further increases in groundfish product form prices.

Some of the volatility in seafood prices is likely to be seasonal or cyclical, coinciding with harvesting periods or holidays such as lent. Provided that these sources of volatility are known to the processor, they do not classify as a form of risk. Time series analysis could be used to distinguish any such variability and a method such as autoregressive integrated moving average (ARIMA) could be used to eliminate seasonal components.

2.6.4 Undeveloped Markets and Incomplete Information

Product form diversification strategies are likely to be most important for newly established fisheries or firms processing relatively few product forms. One problem that emerges is that in order to apply portfolio analysis to product forms for which markets have yet to be developed, one requires yet to be generated data from which to calculate a variance-covariance matrix among alternative product forms. In other cases, price data is either simply not collected or firms are reluctant to provide data fearing that symmetric information among firms may cause them to lose market share. This problem could be addressed by assuming that the volatility in returns of the proposed product would resemble the volatility of an identical product made from a similar species. Given the high correlations among species for a particular product form as discussed in the previous section, this would appear to be a reasonable assumption. Developing a variance-covariance matrix using this data and arriving at an estimate for the expected rate of return would allow for the derivation of the minimum variance portfolio frontier.

CHAPTER 3

DIVERSIFICATION OF PACIFIC WHITING PRODUCT FORMS

3.1 Introduction

Pacific whiting, *Merluccius productus*, is used as a case study to determine the trade-off between expected benefits and risk to seafood processors resulting from portfolio diversification of alternative product forms from a single species. Diversification strategies are analyzed using two different methods. The first approach is based on the direct application of portfolio theory from the finance literature, using the *E-V* decision model. This model investigates diversification strategies based on per unit of production net returns but does not incorporate the total volume of fish caught. The second approach, the *I-V* model, incorporates total expected net income resulting from a specified level of catch rather than using expected return. As will be shown, these two methods provide significantly different minimum variance portfolio frontiers and hence, different efficient portfolio sets.

3.2 Model Selection

The Markowitz or full-covariance model, as discussed in section 2.2, is used in this analysis for the derivation of minimum variance portfolio frontiers of alternative product forms. This model specification is used since there are relatively few products being considered for portfolio selection and it includes all sources of variability between products. However, since asset betas provide a simple summary statistic as to the relative volatility of alternative products and portfolios, they are also estimated using the single-index model, although not used directly in portfolio construction. The market index used for estimating betas is an average of the product form returns being considered for portfolio selection, as discussed in section 2.6.2.

In surveys conducted of Pacific whiting processors (Tuininga, 1995), firms indicated that there are no risk-free alternatives available to them. Therefore, the Tobin model specification does not accurately describe the set of portfolio choices available to seafood processors. One exception was a firm that provided fish processing as a service, but was not responsible for sales of the end products and thus not susceptible to price risk.

3.3 Data

Over 70 percent of Pacific whiting is currently processed into surimi while the remaining 30 percent is processed into headed and gutted (H&G), fillets, and meal. Alternative product forms such as fillet blocks, minced blocks, breaded portions, steaks, whole, and fresh surimi analogs are potential end products that may be processed from Pacific whiting. However, in order to construct the variance-covariance matrix of returns among alternative products used in the Markowitz model, returns for a given product form must be estimated from a time series of wholesale prices and finished product costs. Since processing and market information do not exist for all of the alternative products, not all products are used in the portfolio selection model. Furthermore, since some of the data for this research were obtained through surveys of shore-based Pacific whiting processors in September of 1995 (Tuininga, 1995), and their processing costs are known to differ slightly from those of off-shore processors (PFMC, 1993), portfolio analysis is only applied to the on-shore processing sector.

3.3.1 Product Form Prices

Domestic processing of large quantities of Pacific whiting has only occurred since 1992. Thus, little historical information exists on market prices for current product forms. Additionally, market price data are not collected for most products and firms are sometimes reluctant to provide data fearing potential loss of market share. Anti-trust laws also prevent the discussion of prices among seafood processors. As discussed in section 2.6.3, there is high correlation in prices between identical product forms from similar species due to substitution. It is, therefore, valid to assume that the volatility in returns of a specific product form likely resembles the volatility experienced by an identical product made from another species. Based on this assumption, published monthly prices for twelve product forms were used to estimate time series for Pacific whiting product form prices.

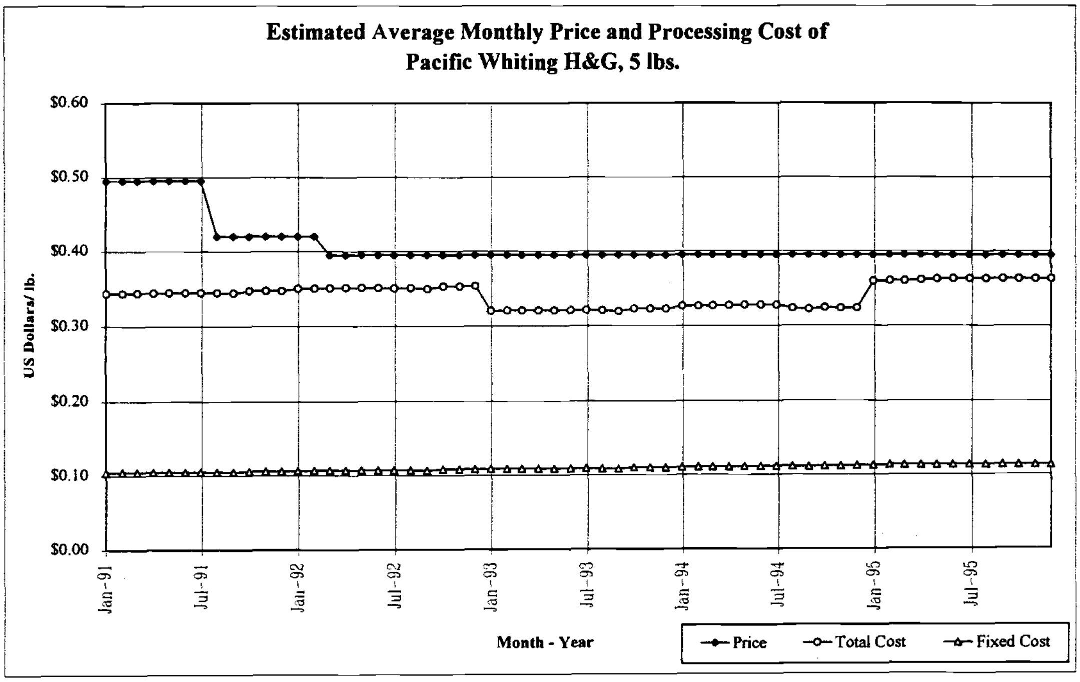
Prices for five product forms produced from Pacific whiting on a per pound basis were estimated using data from the *Fisheries Market News Report* (Urner Barry, 1984-94; NMFS, 1995). Prices for seven other product forms were estimated using data from *Seafood-Price Current* (Urner Barry, 1989-95). Based on known price relationship information provided by processor surveys (Tuininga, 1995), prices for products used for estimation purposes were adjusted so that they matched an average of market prices observed by Pacific whiting processors in September of 1995. Expected prices were used for product forms not currently in production. Table 3.1 provides a summary of the product forms used for estimation purposes, abbreviations used herein, and their respective price adjustments. Figures 3.1.1 - 3.1.4 depict estimated price time series for selected product forms. Since prices for IQF and shatterpack fillets were first published by Urner Barry (1989-95) in October of 1991, these product forms limit the number of observations used in deriving the variance-covariance matrix to 51.

Table 3.1 Product Forms of Portfolio Selection Model

PRODUCT FORM	PRODUCT DESCRIPTION	LOT WEIGHT	SPECIES	ORIGIN	ABBR.	PRICE ADJUST.	DATA SOURCE*
H & G		5 lbs.	Whiting	S. America	H&G	-0.03	S-P C
Blocks		16.5x4 lbs.	Whiting	S. America	Blk.	-0.15	S-P C
Minced Blocks		16.5x4 lbs.	Ak. Pollock	Domestic	M. Blk.	-0.02	FMNR
Surimi	FA Grade	16.5x4 lbs.	Ak. Pollock	Domestic	Suri.	-0.23	S-P C
Layerpack Fillets	skinless / boneless	10 lbs.	Whiting	S. America	Layr.-a	none	FMNR
Layerpack Fillets	skin-on / boneless	10 lbs.	Whiting	S. America	Layr.-b	none	FMNR
Shatterpack Fillets	2-4 oz., skinless / boneless	3x15 lbs.	Ak. Pollock	Domestic	Shat.-a	-0.35	S-P C
Shatterpack Fillets	4-6 oz., skinless / boneless	3x15 lbs.	Ak. Pollock	Domestic	Shat.-b	-0.35	S-P C
IQF Fillets	2-4 oz., skinless / boneless	bulk	Ak. Pollock	Domestic	IQF -a	none	S-P C
IQF Fillets	4-6 oz., skinless / boneless	bulk	Ak. Pollock	Domestic	IQF -b	-0.10	S-P C
Breaded Portions	2-4 oz., cooked	6 lbs.	Whiting	S. America	Brd. -a	-0.35	FMNR
Breaded Portions	2-4 oz., raw	6 lbs.	Whiting	S. America	Brd. -b	-0.35	FMNR

* S-P C = *Seafood-Price Current* (Urner Barry, 1989-95)
FMNR = *Fisheries Market News Report* (Urner Barry, 1989-94; NMFS, 1995)

No trend or seasonal patterns are evident from Figures 3.1.1 - 3.1.4, nor were any patterns visible after differencing the time series. Furthermore, due to the limited number of observations, additional time series analysis was not used to test for seasonality in the price data.



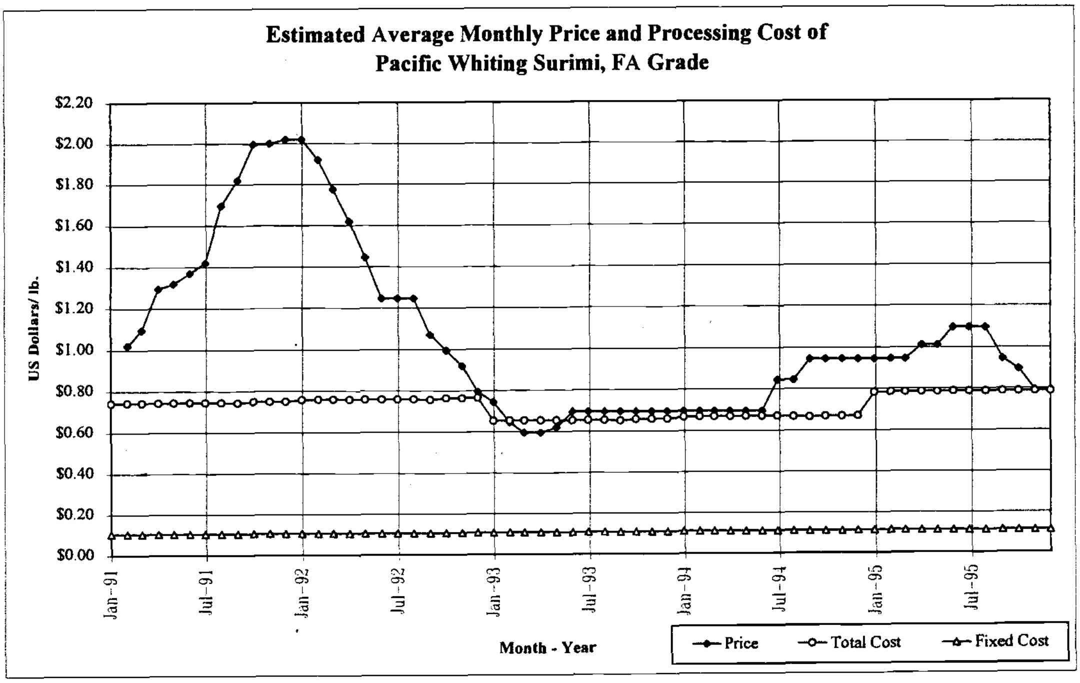
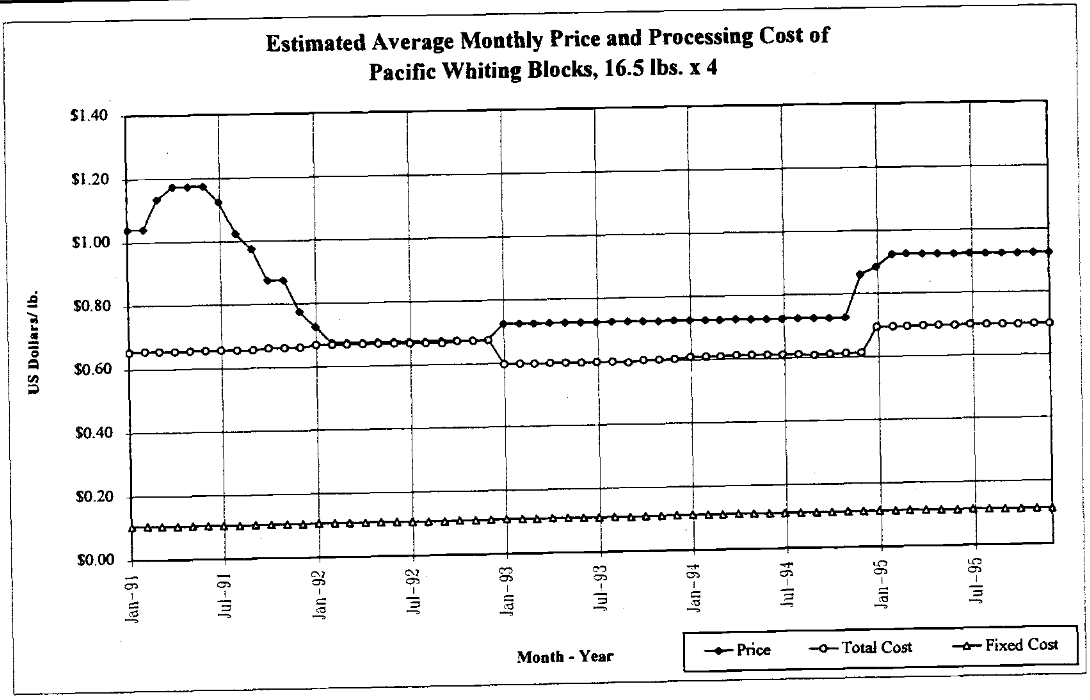


Figure 3.1.1 Estimated Price and Processing Cost for H&G and Surimi



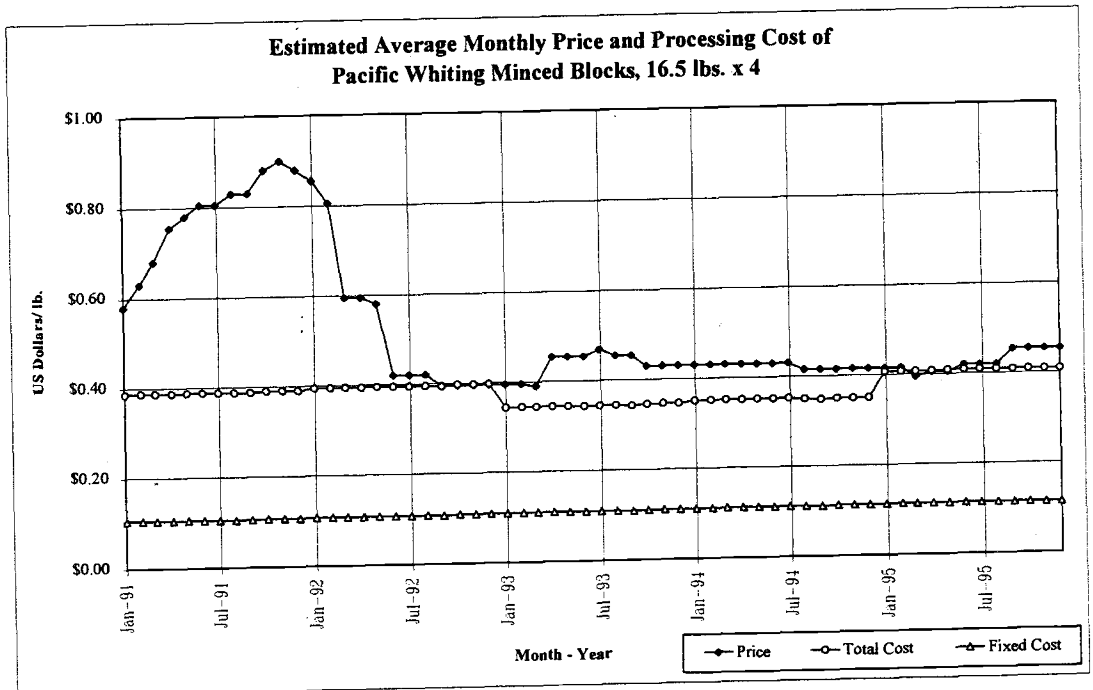


Figure 3.1.2 Estimated Price and Processing Cost for Blocks and Minced Blocks

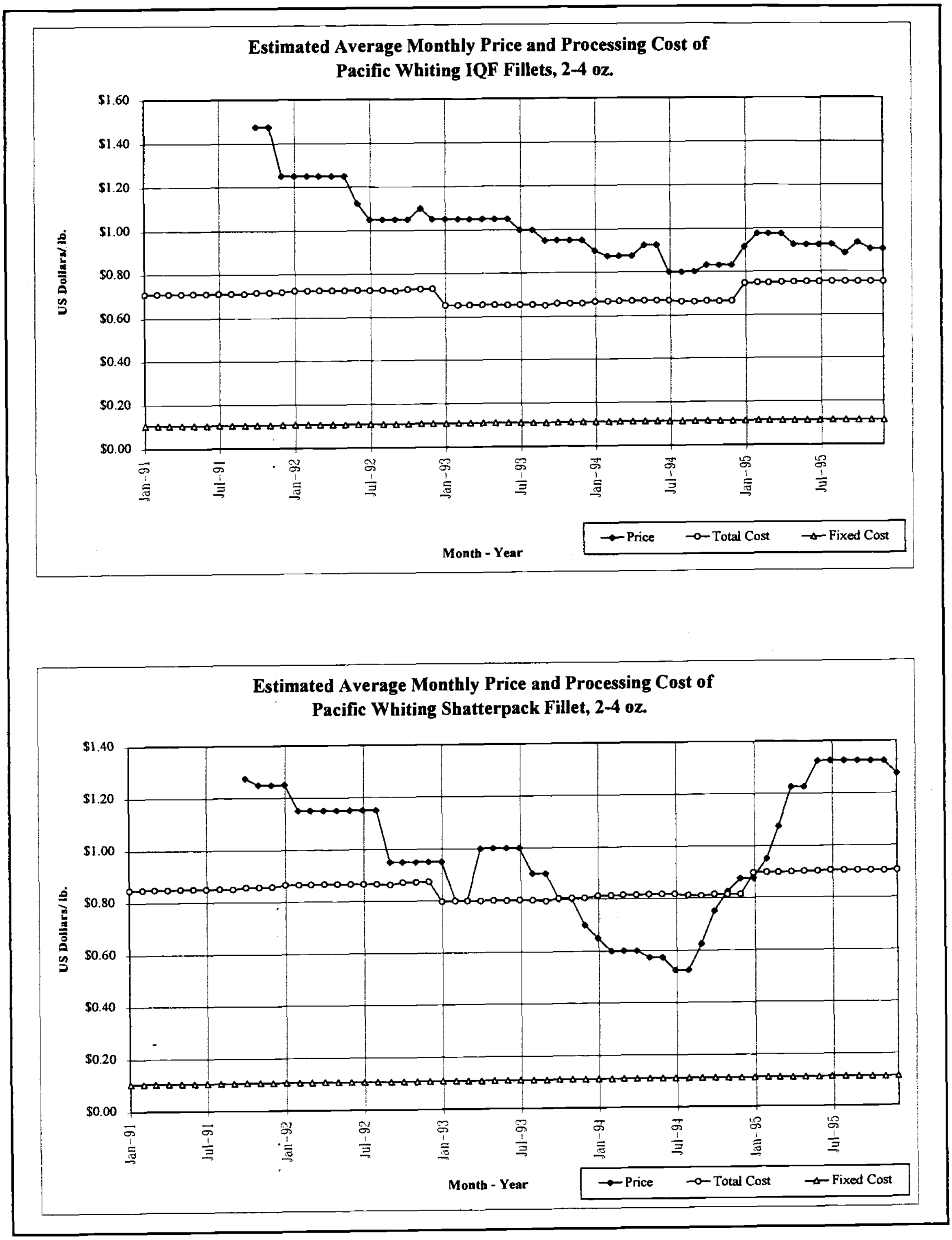
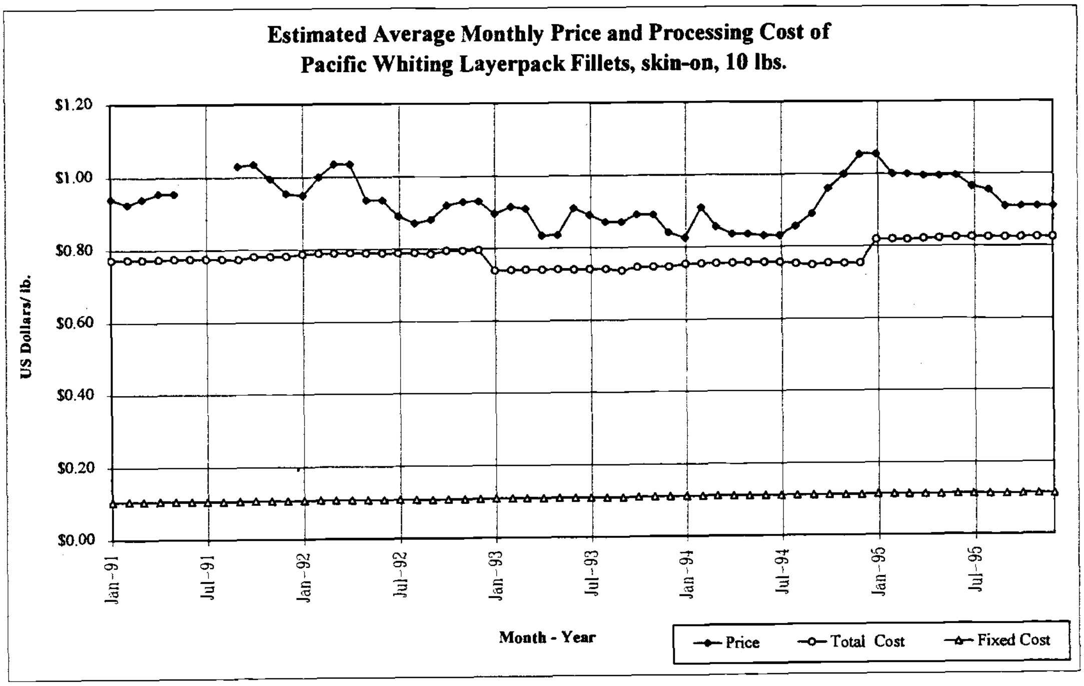


Figure 3.1.3 Estimated Price and Processing Cost for IQF and Shatterpack Fillets



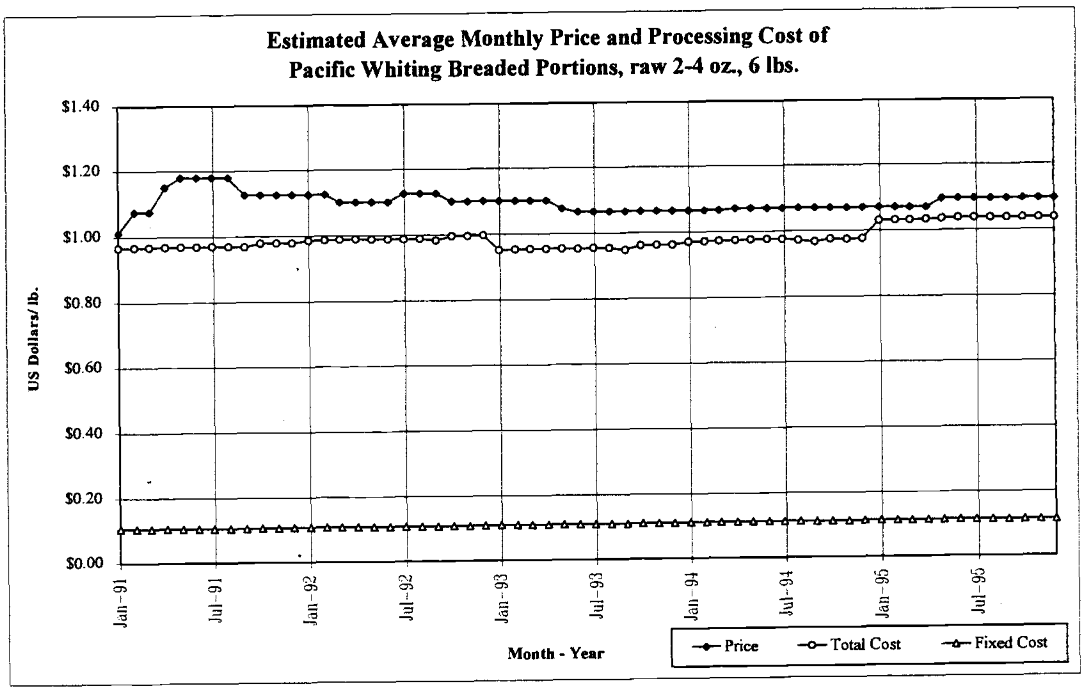


Figure 3.1.4 Estimated Price and Processing Cost for Layerpack Fillets and Breaded Portions

3.3.2 Processing Costs

Average processing costs per finished pound for product forms currently produced were obtained through surveys with Pacific whiting processors while costs of producing alternative product forms were based on processors' best estimates (Tuininga, 1995). Fixed costs per pound of finished product in September of 1995 are broken down by category in Table 3.2. All processors surveyed, with one exception, indicated that they processed other species besides Pacific whiting. Most processed between three and six

Table 3.2 Processing Fixed Costs Per Finished Pound

Administrative Salaries	0.042
Maintenance	0.004
Utilities	0.005
Communications	0.003
Business Taxes	0.002
Insurance	0.010
Misc. Admin. (technicians)	0.006
Administrative Supplies	0.003
Interest	0.020
Depreciation	0.020
Total Fixed Costs	0.114

additional species. While Pacific whiting accounted for the majority of processed fish for firms in terms of round weight, whiting generally made up only 20 to 40 percent of a firm's total revenues. Since fixed costs are inseparable among species and product forms, they are allocated equally among all finished product. A summary of the variable costs incurred by Pacific whiting processors by product form is provided in Table 3.3.

Variable costs are heavily influenced by raw product cost, product recovery rates (PRR), labor, and additional processing materials. Total and fixed cost per finished pound are depicted in Figures 3.1.1 - 3.1.4. Variable costs are the difference between these two costs.

The average cost per pound of unprocessed Pacific whiting to processors in Oregon in 1991 was $0.0464 (ex-vessel price), which increased slightly to $0.0469 in 1992 (Carter, 1995). Due to a decline in the market price for surimi, fishermen received $0.0289 and $0.0299 per pound in 1993 and 1994, respectively. Raw Pacific whiting average price increased to $0.0475 in 1995 following an increase in surimi prices beginning in July of 1994.

Table 3.3 Processing Variable Costs Per Finished Pound

				Minced	Layer./Shatter. Fillet		IQF	Breaded Portions*	
	H&G	Surimi	Blocks	Blocks	sknls/bnls	skin-on	Fillet	raw	cooked
Cost / round lb.	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Fish Tax**	0.001	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.001
Yield (PRR)	53.8%	16.1%	23.0%	33.0%	23.0%	31.0%	23.0%	37.7%	37.7%
Raw Product Cost (w/tax)	0.094	0.314	0.220	0.153	0.220	0.163	0.220	0.134	0.134
Labor and Benefits	0.060	0.120	0.250	0.050	0.400	0.375	0.250	0.505	0.505
Direct Materials									
Ingredients		0.089		0.020				0.110	0.140
Packaging	0.050	0.037	0.025	0.030	0.060	0.060	0.060	0.060	0.060
Manufacturing Overhead	0.050	0.131	0.100	0.050	0.120	0.120	0.120	0.120	0.120
Support Labor and Benefits									
Fuel									
Fish Waste Removal									
Water and Sewage									
Electricity									
Observers / Inspection									
Product Storage									
Shipping / Transportation									
Marketing									
Maintenance									
Total Variable Costs	0.254	0.690	0.595	0.303	0.800	0.718	0.650	0.929	0.959

* Breading is 39% of finished weight

** Tax rate of 1.09% of landed value, beginning in1992 (Carter, 1995b)

Since time series of processing costs by product form were not available, producer price indices (U.S. Department of Labor, 1992-95) were used to estimate costs experienced by processors prior to September of 1995. The producer price index for capital equipment was used for estimating time series of costs for ingredients, labor, and overhead while packaging used an index specific to the folding sanitary containers used by processors.

3.3.3 Estimated Returns

Monthly processing costs and wholesale market prices have been estimated assuming processing occurs throughout the year. However, Pacific whiting landings occur only from April 15th until the TAC has been reached, generally between June and August depending on the size of the TAC and shoreside processing capacity[1]. Hence, processing costs are not incurred in months that have no landings. In addition, most processors have pre-arranged contracts to sell the majority of their product at the beginning of the fishing season. What is not contracted for is usually stored for periods of less than two months before it is sold. Thus, storage costs are not generally a significant expense for Pacific whiting processors. Since intra-year variation in processing costs is relatively small (approximately 4 percent for surimi) and forward contracting occurs, the assumption of processing and sales throughout the year should not significantly alter the analysis. Although forward contracting provides an opportunity for processors to "sell short" product, it was not found to be a prevalent activity in the

[1] In 1996 the Pacific whiting season opening changed to May 15th.

industry (Tuininga, 1995) and therefore equations allowing for negative proportions of product forms in portfolios were not incorporated into the portfolio model.

Proportional returns per pound of finished product were estimated using a variation on the generalized equation 2.17,

$$r_{i,t} = \frac{P_{i,t} - C_{i,t}^{Raw\ Product} - C_{i,t}^{Variable} - C_{i,t}^{Fixed}}{C_{i,t}^{Raw\ Product} + C_{i,t}^{Variable} + C_{i,t}^{Fixed}}.$$

Correlation coefficients of returns estimated for the twelve alternative product forms ranged from -0.51 to 0.90. Estimated returns of blocks were negatively correlated with the returns of most other product forms. Returns from H&G were negatively correlated with returns from surimi and shatterpack fillets. Due to their negative correlation coefficients with different product forms, blocks and H&G are likely to be important products in reducing variation in the expected rate of return sought by processors. Correlation coefficients are provided in Table 3.4.

Table 3.4 Product Form Correlation Coefficients of Estimated Returns

	H&G	Blk.	M. Blk.	Suri.	Layr.-a	Layr.-b	Shat.-a	Shat.-b	IQF -a	IQF -b	Brd. -a	Brd. -b
H&G	1.0000											
Blk.	-0.0500	1.0000										
M. Blk.	0.3972	-0.0856	1.0000									
Suri.	-0.0462	-0.2664	0.8051	1.0000								
Layr.-a	0.3954	0.1255	0.2992	0.1885	1.0000							
Layr.-b	0.1338	0.0989	0.3558	0.4778	0.7736	1.0000						
Shat.-a	-0.5062	0.1272	0.2854	0.4752	0.1601	0.1995	1.0000					
Shat.-b	-0.1806	-0.1321	0.2593	0.3599	0.3495	0.2224	0.7755	1.0000				
IQF -a	0.3376	-0.3551	0.7675	0.6425	0.4389	0.3561	0.3395	0.5603	1.0000			
IQF -b	0.1954	-0.4468	0.5164	0.4390	0.3016	0.1517	0.4141	0.7156	0.9021	1.0000		
Brd. -a	0.2569	-0.5043	0.2533	0.1826	0.1024	-0.0665	0.1849	0.5949	0.6012	0.8035	1.0000	
Brd. -b	0.6569	-0.5237	0.5364	0.3560	0.2983	0.1181	-0.0359	0.3847	0.7452	0.7634	0.8047	1.0000

3.4 Portfolio Risk and Expected Returns

The equations used to solve for the minimum variance portfolio frontier of the Markowitz model, as developed in section 2.2, are

$$\begin{aligned} \textit{Minimize:} \quad & V = \mathbf{X'CX} \\ \textit{Subject to:} \quad & E = \mathbf{X'R} \\ & \mathbf{X'L} = 1 \\ & x_i \geq 0 \end{aligned}$$

A non-linear programming model using the GAMS (Brooke et al., 1992) software package and the MINOS solver (Murtagh and Saunders, 1987) was developed to solve the portfolio model equations using vector optimization (Appendix A). Due to the size of Pacific whiting, processors indicated that only 30 percent of fillets are 4-6 oz. or larger. Thus, an additional constraint on IQF and shatterpack fillets for this size was used. Betas were estimated using SAS and the bivariate regression equation $r_{i,t} = \alpha_i + \beta_i r_{m,t} + \varepsilon_{i,t}$ where $r_{m,t} = \sum_{i=1}^{n} r_{i,t}$ as discussed in sections 2.3 and 2.6.2. Risk, expected returns, and betas of individual product forms are provided in Table 3.5.

Portfolio risk, return, beta, and product mix information generated by the model for each portfolio are provided in Table 3.6. As discussed in section 2.3, product form beta estimates from Table 3.5 are used to calculate betas for each of the portfolios using equation 2.11. Individual product forms, the minimum variance portfolio frontier, and product form mix of selected portfolios are depicted in Figure 3.2. The constraint on the production of 4-6 oz. fillets prevents the model from increasing the proportion of these product forms in portfolios greater than 30 percent. This causes the point for 4-6 oz. IQF fillets to lie outside of the frontier and also explains the "flattened" slope between portfolio 2 and 23. When this constraint is incorporated in the model and binding, the model chooses to produce 2-4 oz. IQF fillets, larger proportions of surimi, and smaller proportions of blocks in portfolios than when the constraint is not included.

Table 3.5 Product Form Parameter Estimates

i	σ_i	P_i	C_i^{Total}	r_i	B_i	α_i	R^2	se
H&G	0.0579	0.40	0.368	0.087	0.349	0.102	0.29	0.086
Blk.	0.1168	0.80	0.708	0.130	0.684	0.066	0.27	0.179
M. Blk.	0.3394	0.43	0.417	0.031	2.279	-0.294	0.81	0.178
Suri.	0.5069	1.10	0.804	0.368	2.459	-0.260	0.58	0.336
Layr.-a	0.0663	0.95	0.913	0.041	0.307	0.027	0.39	0.061
Layr.-b	0.0719	0.90	0.832	0.082	0.247	0.127	0.24	0.063
Shat.-a	0.2608	1.10	0.913	0.205	1.383	-0.194	0.41	0.203
Shat.-b	0.2563	1.15	0.913	0.260	1.523	0.053	0.51	0.180
IQF -a	0.2150	0.95	0.763	0.245	1.569	0.055	0.77	0.103
IQF -b	0.2369	1.00	0.763	0.311	1.557	0.139	0.63	0.146
Brd. -a	0.1231	1.10	1.073	0.025	0.703	0.034	0.49	0.114
Brd. -b	0.0348	1.05	1.043	0.007	0.215	0.050	0.56	0.030

Of the product forms used in the portfolio selection model, those with low expected returns generally experienced low volatility in prices while products with high expected returns were associated with greater price risk. This phenomenon follows the trend experienced in asset markets. High return / high risk portfolios consist primarily of surimi, and IQF fillets. Medium return / medium risk portfolios are primarily made up of IQF fillets, blocks, and H&G. Raw breaded portions, H&G, and blocks are used in low return / low risk portfolios.

Table 3.6 *E-V* Portfolio Construction

Portfolio	Risk	Return	Beta	H&G	Blk.	M. Blk.	Suri	Layr. -a	Layr. -b	Shat. -a	Shat. -b	IQF -a	IQF -b	Brd. -a	Brd. -b
				Product Form Mix (%)											
1	0.451	0.360	2.332				0.860						0.140		
2	0.405	0.353	2.222				0.737						0.263		
3	0.378	0.346	2.153				0.660					0.040	0.300		
4	0.359	0.339	2.102				0.603					0.097	0.300		
5	0.341	0.332	2.052				0.546					0.154	0.300		
6	0.323	0.325	2.001				0.489					0.211	0.300		
7	0.306	0.318	1.950				0.433					0.267	0.300		
8	0.290	0.311	1.900				0.376					0.324	0.300		
9	0.275	0.304	1.849				0.319					0.381	0.300		
10	0.260	0.297	1.796		0.041		0.300					0.358	0.300		
11	0.246	0.290	1.743		0.084		0.283					0.333	0.300		
12	0.231	0.283	1.690		0.126		0.266					0.307	0.300		
13	0.217	0.276	1.638		0.169		0.249					0.282	0.300		
14	0.203	0.269	1.585		0.212		0.232					0.257	0.300		
15	0.189	0.262	1.532		0.254		0.215					0.231	0.300		
16	0.175	0.255	1.479		0.297		0.198					0.206	0.300		
17	0.162	0.248	1.426		0.339		0.181					0.180	0.300		
18	0.149	0.241	1.373		0.382		0.163					0.155	0.300		
19	0.136	0.234	1.320		0.424		0.146					0.129	0.300		
20	0.124	0.227	1.267		0.467		0.129					0.104	0.300		
21	0.113	0.220	1.214		0.509		0.112					0.079	0.300		
22	0.103	0.213	1.161		0.552		0.095					0.053	0.300		
23	0.094	0.206	1.108		0.594		0.078					0.028	0.300		
24	0.087	0.199	1.055	0.009	0.627		0.063					0.001	0.300		
25	0.081	0.192	1.002	0.073	0.581		0.046						0.300		
26	0.076	0.185	0.951	0.136	0.537		0.030						0.297		
27	0.072	0.178	0.909	0.190	0.509		0.029						0.272		
28	0.068	0.171	0.868	0.244	0.481		0.028						0.248		
29	0.064	0.164	0.827	0.297	0.453		0.027						0.223		
30	0.060	0.157	0.786	0.351	0.425		0.026						0.199		
31	0.057	0.150	0.742	0.389	0.394		0.023		0.016	0.001			0.177		
32	0.054	0.143	0.701	0.425	0.353		0.018		0.036	0.015			0.153		
33	0.051	0.136	0.661	0.462	0.311		0.013		0.056	0.030			0.129		
34	0.048	0.129	0.620	0.498	0.270		0.008		0.076	0.044			0.105		
35	0.046	0.122	0.579	0.534	0.228		0.002		0.096	0.059			0.081		
36	0.043	0.115	0.540	0.576	0.187				0.111	0.072			0.053		
37	0.041	0.108	0.507	0.596	0.158				0.117	0.080			0.030		0.019
38	0.040	0.101	0.487	0.548	0.157				0.113	0.076			0.024		0.082
39	0.038	0.094	0.466	0.500	0.155				0.109	0.072			0.018		0.145
40	0.036	0.087	0.446	0.453	0.153				0.106	0.068			0.012		0.209
41	0.035	0.080	0.425	0.405	0.152				0.102	0.063			0.006		0.272
42	0.033	0.073	0.405	0.355	0.151				0.099	0.059					0.336
43	0.031	0.066	0.387	0.285	0.157				0.096	0.049					0.413
44	0.030	0.059	0.369	0.214	0.164				0.094	0.039					0.489
45	0.028	0.052	0.351	0.143	0.170				0.092	0.029					0.566
46	0.027	0.045	0.333	0.073	0.176				0.089	0.019					0.642
47	0.025	0.038	0.315	0.002	0.183				0.087	0.009					0.719
48	0.025	0.031	0.295		0.165				0.047	0.001					0.787
49	0.026	0.024	0.280		0.138										0.862
50	0.028	0.017	0.253		0.081										0.919
51	0.033	0.010	0.226		0.024										0.976

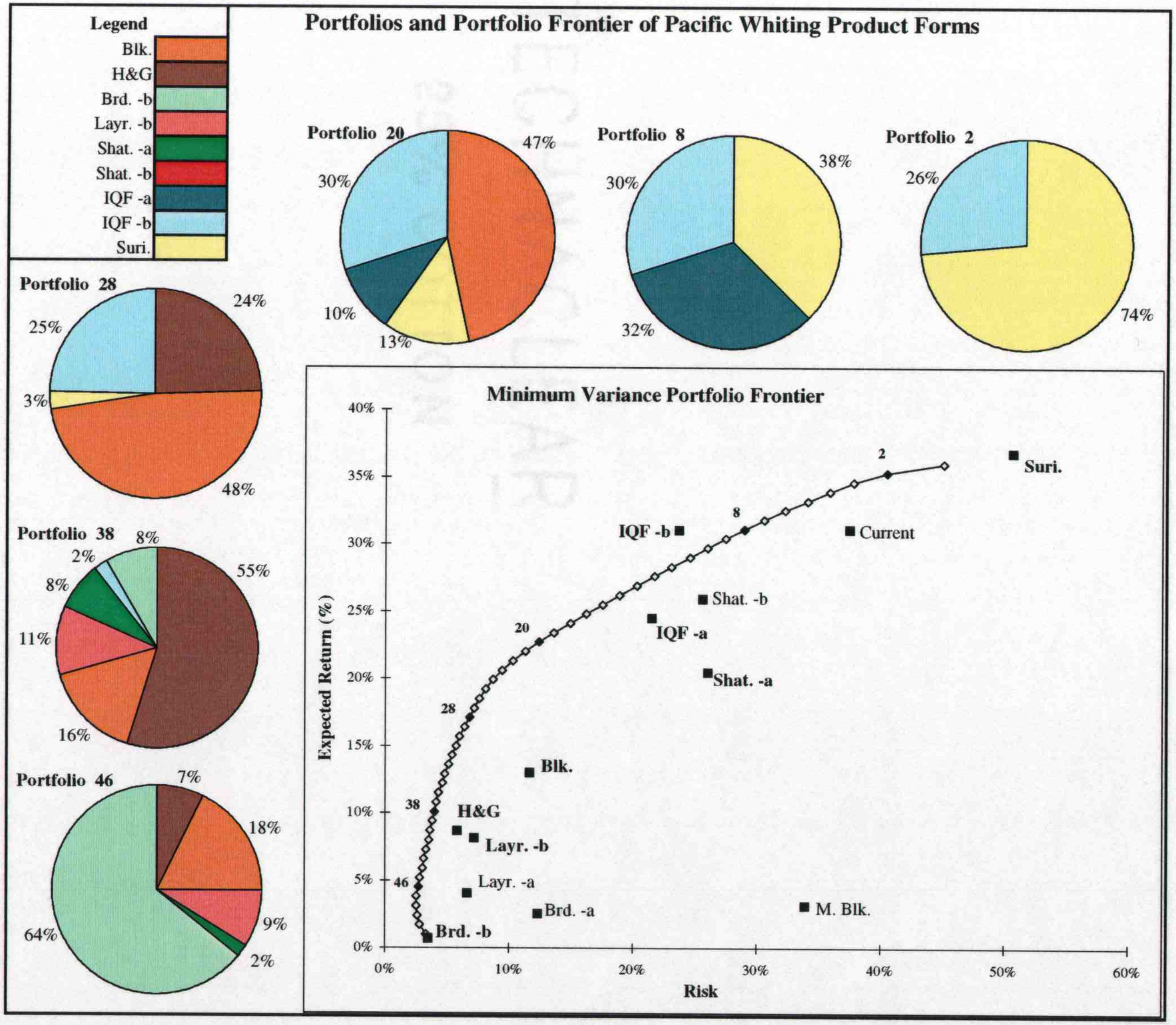


Figure 3.2 Portfolios and *E-V* Portfolio Frontier of Product Forms

The model selects the production of blocks through a wide range of portfolios associated with various levels of risk. This results because blocks provide significant risk reduction due to their low covariation with all other product forms, especially IQF fillets and breaded products. The model chooses to produce 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 since the returns and risk reducing performance of these product forms are relatively low.

If Pacific whiting processors produce a current product mix of 70 percent KA grade surimi, 15 percent IQF fillets and 15 percent H&G, then their production strategy could be characterized as a high risk / high return portfolio of products. This product mix is plotted in *E-V* space in Figure 3.2 and denoted as "current". Given the proximity of this product mix to the minimum variance portfolio frontier, processors may be able to reduce risk (increase return) without sacrificing expected return (increasing risk) by changing the product mix. For example, by producing less H&G and more IQF fillets than the current product mix, processors could obtain a product mix similar to portfolio 8 in Figure 3.2 and Table 3.6 which would reduce risk while obtaining the same expected return.

A problem that emerges when utilizing this methodology to evaluate the risk and expected return tradeoff among alternative portfolios is that it approaches diversification on a per unit level. Clearly, processors do not invest in product forms in the same sense that investors purchase financial assets. Rather, processors make production decisions that are also based on the product recovery rates of the alternative product forms and the quantity of fish landed. However this approach does provide some insight into the long-run risk and profitability of the various products. In addition, this method would also be useful to seafood brokers since they often buy and sell seafood in a commodities-based type of market. The following model attempts to more accurately reflect potential product form portfolio choices available to seafood processors.

3.5 Portfolio Risk and Expected Net Income

It is assumed that fish processors attempt to maximize net income given the quantity of fish landed. In doing so, they incorporate expected prices, processing costs, product recovery rates, and the market risk of the alternative products in their production decisions. As evident from Table 3.3, yields vary significantly among the different products and have an important impact on net income. For example, 1,186,000 lbs. of H&G could be processed from 1,000 mt of raw fish. However the same quantity of whiting would only produce 355,000 lbs. of surimi.

Extending this example to the portfolio model, an alternative non-linear programming model is developed to maximize expected net income given a specified level of risk. The model is solved over the available range of risk to construct a maximum expected net income portfolio frontier. The model specification can be expressed mathematically as:

Maximize: $$I = \sum_{i=1}^{n} Q_i^F \left(P_i - C_i^{Variable} \right) \tag{3.1}$$

Subject to: $$\sum_{i=1}^{n} x_i = 1 \tag{3.2}$$

$$x_i \geq 0 \tag{3.3}$$

$$\sigma_P = \sqrt{V} = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n} x_i x_j \sigma_{i,j}} \tag{3.4}$$

$$L = \sum_{i=1}^{n} Q_i^R \tag{3.5}$$

$$Q^T = \sum_{i=1}^{n} Q_i^F \tag{3.6}$$

$$Q_i^F = Q_i^{R^*} PRR_i \tag{3.7}$$

$$Q_i^F = x_i Q^T \tag{3.8}$$

where Q_i^R and Q_i^F represent the raw and finished weight used in producing each product form *i*, respectively. Q^T is the combined finished weight of the products and *I* represents total net income. *L* is the quantity of fish landed, fixed at 1,000 mt, and PRR_i equals the product recovery rates of the alternative product forms.

Model results are listed in Table 3.7 and depicted in Figure 3.3. Net income is highest in portfolio 44 which consists of 70 percent H&G, 27 percent 4-6 oz. IQF fillets, and 3 percent 4-6 oz. shatterpack fillets. The beta of this portfolio is 0.71, indicating that the risk associated with this portfolio is below the average risk of all product forms. While the net income per pound of H&G ($0.15) is relatively low compared to 4-6 oz. IQF fillets ($0.35) and KA grade surimi ($0.41), the higher product recovery rate for H&G offsets the lower net income per unit when the total quantity of fish landed is incorporated into the model. In addition, the low volatility in returns of H&G makes this an important low risk product form to processors.

Table 3.7 *I-V* Portfolio Construction

				Product Form Mix (%)											
Portfolio	Risk	Net Inc.	Beta	H&G	Blk.	M. Blk.	Suri	Layr. -a	Layr. -b	Shat. -a	Shat. -b	IQF -a	IQF -b	Brd. -a	Brd. -b
1	0.473	147,475	2.382				0.915						0.085		
2	0.464	148,018	2.362				0.892						0.108		
3	0.455	148,573	2.341				0.869						0.131		
4	0.446	149,139	2.320				0.846						0.154		
5	0.437	149,719	2.299				0.822						0.178		
6	0.428	150,312	2.278				0.799						0.201		
7	0.419	150,920	2.256				0.775						0.225		
8	0.410	151,544	2.234				0.751						0.249		
9	0.401	152,184	2.212				0.727						0.273		
10	0.392	152,843	2.190				0.702						0.298		
11	0.383	153,145	2.154	0.017			0.683						0.300		
12	0.374	153,422	2.116	0.035			0.665						0.300		
13	0.365	153,707	2.077	0.053			0.647						0.300		
14	0.356	154,001	2.039	0.071			0.629						0.300		
15	0.347	154,304	2.001	0.089			0.611						0.300		
16	0.338	154,617	1.963	0.107			0.593						0.300		
17	0.329	154,940	1.925	0.125			0.575						0.300		
18	0.320	155,274	1.886	0.143			0.557						0.300		
19	0.311	155,620	1.848	0.161			0.539						0.300		
20	0.302	155,977	1.809	0.180			0.520						0.300		
21	0.293	156,348	1.771	0.198			0.502						0.300		
22	0.284	156,732	1.732	0.216			0.484						0.300		
23	0.275	157,131	1.693	0.235			0.465						0.300		
24	0.266	157,545	1.654	0.253			0.447						0.300		
25	0.257	157,976	1.615	0.272			0.428						0.300		
26	0.248	158,425	1.575	0.291			0.409						0.300		
27	0.239	158,893	1.536	0.309			0.391						0.300		
28	0.230	159,381	1.496	0.328			0.372						0.300		
29	0.221	159,893	1.456	0.347			0.353						0.300		
30	0.212	160,429	1.416	0.366			0.334						0.300		
31	0.203	160,992	1.375	0.385			0.315						0.300		
32	0.194	161,585	1.334	0.405			0.295						0.300		
33	0.185	162,212	1.293	0.425			0.275						0.300		
34	0.176	162,877	1.251	0.444			0.256						0.300		
35	0.167	163,585	1.208	0.465			0.235						0.300		
36	0.158	164,342	1.164	0.485			0.215						0.300		
37	0.149	165,159	1.120	0.506			0.194						0.300		
38	0.140	166,047	1.074	0.528			0.172						0.300		
39	0.131	167,025	1.026	0.551			0.149						0.300		
40	0.122	168,121	0.976	0.575			0.125						0.300		
41	0.113	170,479	0.893	0.551								0.149	0.300		
42	0.104	172,043	0.829	0.604								0.096	0.300		
43	0.095	173,828	0.762	0.658								0.042	0.300		
44	0.086	175,321	0.710	0.700							0.030		0.270		
45	0.079	175,273	0.693	0.709							0.214		0.076		
46	0.068	174,976	0.628	0.763							0.203		0.033		
47	0.059	174,575	0.551	0.828							0.172				
48	0.050	172,131	0.459	0.902						0.036	0.061				
49	0.041	156,752	0.455	0.756	0.035				0.064	0.103					0.043
50	0.032	126,389	0.377	0.366	0.100				0.075	0.055					0.404

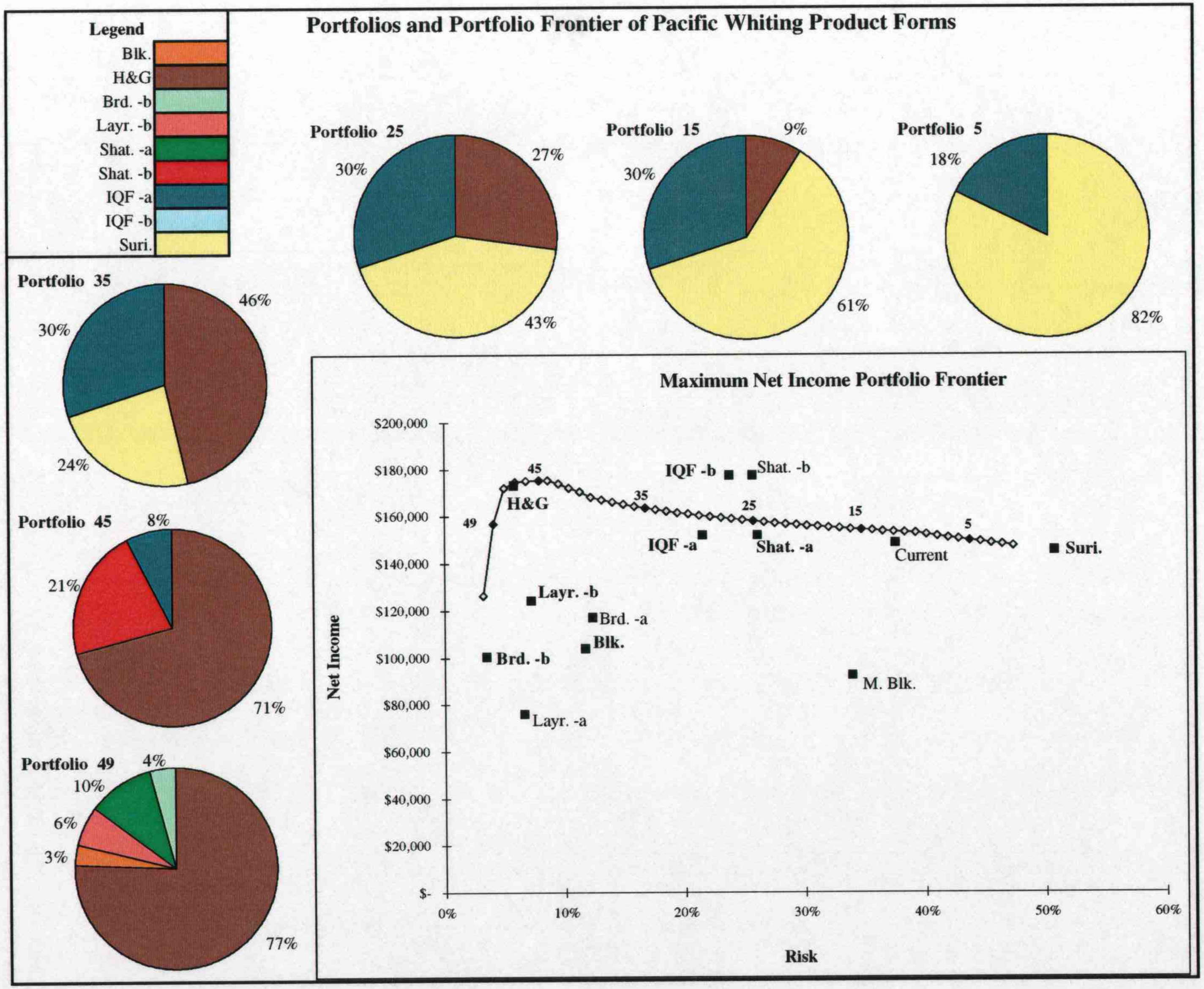


Figure 3.3 Portfolios and *I-V* Portfolio Frontier of Product Forms

In Figure 3.3, the net income of individual products are plotted with the portfolio frontier. The points for 4-6 oz. IQF and shatterpack fillets lie outside the frontier due to the additional constraint that these products can account for a maximum of 30 percent of total production. Surimi, 4-6 oz. IQF fillets, and H&G are the primary product forms selected by the model throughout the range of risk. However, portfolios on the negatively sloped portion of the frontier are inefficient in that the same net income could be achieved with less risk by changing production strategies to be similar to the portfolio combinations on the positively sloped portion of the frontier. As noted in Section 2.6.1, this assumes that markets for such product forms exist. The model chooses to produce shatterpack rather than IQF fillets as the model moves from higher to lower levels of risk. This is the result of lower correlation between returns of H&G with shatterpack fillets than with IQF fillets, as reflected in Table 3.4. This model also assumes that all larger whiting can be sorted out and selected for 4-6 oz. fillet production.

As in the previous model, a point approximating the current product mix of Pacific whiting processors is also plotted in Figure 3.3. The location of this point in risk and net income space indicates that, given the prevailing prices and processing costs, firms may be able to achieve higher profits by shifting production away from surimi and into greater quantities of H&G product. This assumes that the additional quantity of H&G supplied to the market will not decrease its price. More realistically, a significant change in the quantity produced of any product form would likely impact the product's price.

3.6 Conclusion

Portfolio selection differs significantly between the *E-V* and *I-V* models. Although the *I-V* model may more applicable to Pacific whiting processors for short-run production decisions, the *E-V* model provides important insight into the long-run return vs. risk trade-off of individual products and may have greater relevance to seafood brokers. Clearly, portfolio diversification on a per unit basis is profoundly different than from a total production perspective. As was evident from the models, while H&G is an important product form in low risk / low return portfolios of the *E-V* model, it is the dominant product form of the efficient *I-V* portfolios. However, continued market development of alternative product forms such as H&G and fillet products would be required in order for processors to realize the potential profits associated with high net income portfolios.

CHAPTER 4

INTEGRATION OF PORTFOLIO ANALYSIS WITH A BIOECONOMIC MODEL OF THE PACIFIC WHITING FISHERY

4.1 Introduction

The application of portfolio analysis to determine diversification strategies for Pacific whiting processors is an important step for firms in attempting to maximize profits given a specific level of risk. Equally important is how these production strategies should be implemented given seasonal fluctuations in the intrinsic qualities of the species in order to optimize the utilization of the resource. This chapter explores inter-year and intra-year processing alternatives through integrating the portfolio model developed in the previous chapter with a bioeconomic model of the Pacific whiting fishery.

4.2 Seasonal Variation in Pacific Whiting

Seasonal changes in the proximate composition of Pacific whiting are similar to those which occur in pollock, cod, and rock sole (Morrissey, 1993; Bernatt-Byrne, 1991). Most importantly, protein content increases throughout spring and summer which results in higher product recovery rates (PRR). These higher PRRs decrease the raw product cost of producing the alternative products. In addition to increasing PRRs through the fishing season, whiting experience rapid weight gain early in the spring and summer which, for younger fish, peaks in August before leveling off. Weight gain for older year classes generally peaks in June (Larkin, 1995). Intra-seasonal weight gain may allow the sustainable yield of the fishery to increase by 10 percent if the harvesting occurred in September rather than April (Dorn, 1992). The increased size of individual fish and yields of Pacific whiting obtained through fishing later in the season offset the decline in total available biomass due to natural mortality. Larkin (1995) found that delaying the season opening from April to May provided an average increase of $13 million in net benefits over a fifteen year period. The delayed opening also increased the sustainable yield of the biomass by 4,000 mt.

4.3 The Pacific Whiting Biological Model

The equations used to model the biological dynamics of the Pacific whiting fishery were first developed using the GAMS programming language by Enriquez (1993). Many of the equations used in this work attempt to simulate an age structured model used to predict stock yields developed by Dorn and Methot (1989, 1991). Updated parameter estimates were obtained from Dorn and co-workers (1993) and Dorn (1994, 1995). Some of the equations of the annual biological model used by Enriquez were adjusted to fit within a monthly model (Appendix B). A monthly model allows for determining production strategies within the processing season that reflect the seasonal variation in the weight and intrinsic characteristics of the fish. The processing season in the model is defined as April through October.

Pacific whiting are recruited into the fishery at age two and are assumed to enter the fishery in January. Whiting can live up to 18 years. However, since few actually survive over the age of 14, fish of age 15 and older are accumulated in a terminal year class. The following equations are used in the biological model to predict the number of fish, N, and fish landed, L, in month, m, of year, y. A glossary of the variables, constants, and indices is provided in Table 4.1.

Recruitment of age two fish:

$$N_{m=1,y,a=2} = R_y \tag{4.1}$$

Initial numbers of whiting by year class:

$$N_{m=1,y=1,a+1} = N^{I}_{a+1} \tag{4.2}$$

Intra-seasonal numbers of whiting:

$$N_{y,m+1,a} = \sum_{c} P^{Mig.}_{a,c} N_{y,m,a} e^{-Z_{y,m,a,c}} \tag{4.3}$$

Numbers of whiting in January:

$$N_{y+1,m=1,a+1} = \left(\sum_{c} N_{y,m=12,a} P^{Mig.}_{a,c} e^{-Z_{y,m=12,a,c}} \right) + N^{T}_{y+1,m=1,a=15,c} \tag{4.4}$$

Numbers of whiting in terminal age class:

$$N^{T}_{y+1,m=1,a=15,c} = N_{y,m=12,a=15} P^{Mig.}_{a=15,c} e^{-Z_{y,m=12,a=15,c}} \tag{4.5}$$

Total mortality:

$$Z_{y,m,a,c} = M + \sum_{s} F_{y,h,a,c,s} \tag{4.6}$$

Fishing mortality by selectivities:

$$F_{y,h,a,c,s} = F^{A}_{y} S_{a,c,s} A^{M}_{y,h,s} \tag{4.7}$$

Table 4.1 Glossary of Variables, Constants, and Indices

Sym.	Endogenous Variables	Sym.	Exogenous Variables / Constants
A^M	Allocation of fishing by month	$B^{Opt.}$	Optimal spawning biomass
A^S	Allocation of landings by sector	$F^{Opt.}$	Optimal fishing mortality
B	Biomass	FC	Fixed Costs
F	Fishing mortality	λ	Coefficients on weight at age equation
F^A	Annual fishing mortality	M	Natural Mortality Rate
I	Discounted net income by product form	N^I	Initial numbers of age 3+ fish (Billions)
I^Y	Annual net income by product form	P^{FW}	Proportion of female weight
L	Landings	$P^{Mig.}$	Proportion migrating to each country
L^C	Landings by country	P^{SMF}	Proportion of sexually mature females
L^{mt}	US onshore landings in mt	PRR	Product recovery rate / Yield
N	Billions of fish	r	Discount rate
N^T	Billions of fish in terminal age class	R	Recruitment of age two fish (Billions)
NPV	Net Present Value / Objective Value	S	Selectivities
Q^F	Quantity of finished products	W	Weight at age
$Q^{F\text{-}Y}$	Annual Quantity of finished products	$W^{Avg.}$	Average weight at age
Q^R	Quantity of raw fish used in each product		
Q^T	Total Quantity of finished product		**Indices**
σ	Covariance between product forms	a	Age of fish, $a=(2,\ldots,15)$
σ^P	Portfolio standard deviation / risk	c	Country, $c=(US,\ Canada)$
x	Proportion of product in portfolio	h	harvest month, $h=(4,\ldots,10)$
Z	Total Mortality Rate	i, j	product forms, $i=(1,\ldots,n)$
		m	month, $m=(1,\ldots,12)$
		s	Fishing sector, $s=(onshore,\ offshore)$
		y	year, $y=(1,\ldots,6)$

Allocation of fishing mortality by month:

$$\sum_{h} A^{M}_{y,h,s} = 1 \qquad 4.8$$

Annual fishing mortality:

$$F^{A}_{y} = F^{Opt.} B_{y} \,/\, B^{Opt.} \qquad 4.9$$

Spawning Biomass:

$$B_{y} = \sum_{a} N_{y,m=1,a} P^{SMF}_{a} P^{FW}_{a} W^{Avg.}_{a} \qquad 4.10$$

Landings:

$$L_{y,h,a,c,s} = N_{y,m,a} F_{y,h,a,c,s} \,/\, Z_{y,m,a,c}\left(1 - e^{-Z_{y,m,a,c}}\right) P^{Mig.}_{a,c} \qquad 4.11$$

Landings by country:

$$L^{C}_{y,c} = \sum_{h,a,s} L_{y,h,a,c,s} \qquad 4.12$$

Seasonal weight at age (Larkin, 1995):

$$W_{a,h} = \lambda^{Const.}_{a} + \lambda^{Lin.}_{a} h + \lambda^{Quad.}_{a} h^{2} + \lambda^{Ln}_{a} \log h \qquad 4.13$$

Allocation of landings by sector:

$$\sum_{s} A^{S}_{s} = 1 \qquad 4.14$$

$$A^{S}_{s} \sum_{a,h,s} L_{y,h,a,c=US,s} W_{a,h} = \sum_{a,h} L_{y,h,a,c=US,s=on} W_{a,h} \qquad 4.15$$

US onshore landings:

$$L^{mt}_{y,h} = \sum_{a} L_{y,h,a,c=US,s=on} W_{a,h} \qquad 4.16$$

The model incorporates two countries, the US and Canada, and two processing sectors, shore-based plants and at-sea processors. Since the focus of the portfolio analysis is on the US shore-based processing industry, the biological model indirectly maximizes landings for this specific sector given a constraint that the minimum female spawning biomass (*B*) remains above a cautionary level of 623 million fish as determined by the National Marine Fisheries Service (Dorn, 1995). The model determines landings by country and sector through fishery migration ($P^{Mig.}$) and fishing selectivity (*S*) variables (Dorn, 1995). Fishing selectivity values are measures of the catchability of fish based on their age and geographic distribution that result from estimated fishery selectivity curves. Alternatively, the model can be constrained to harvest at specific allocations. Selectivities and other age-specific characteristic data are provided in Table 4.2. For the purposes of this analysis, the US harvest of Pacific whiting was arbitrarily allocated equally between the onshore and offshore sectors. Historically, the majority of Pacific whiting has been processed by the offshore fleet. However, beginning in 1992, there has been an increasing trend in the quantity of fish processed in shore-based plants. In 1992, 27 percent of the US harvest was processed at shore-based plants followed by 30 percent in 1993 and 29 percent in 1994 (Dorn et al., 1993: Dorn, 1994; Dorn, 1995). In 1993, the Pacific Fishery Management Council (1993) voted to allocate 40 percent of the landings to shore-based processors and 60 percent to be processed at sea for the 1994-96 harvest seasons.

Table 4.2 Pacific Whiting Characteristics

a	2	3	4	5	6	7	8	9	10	11	12	13	14	15
S														
US, Onshore	0.180	0.400	0.670	0.860	0.950	0.980	1.000	1.000	1.000	0.980	0.910	0.750	0.450	0.190
US, Offshore	0.070	0.310	0.720	0.940	0.990	1.000	1.000	0.990	0.980	0.940	0.850	0.660	0.410	0.200
Canada	0.380	0.430	0.480	0.550	0.610	0.690	0.770	0.860	0.950	1.000	0.930	0.710	0.410	0.190
$P^{Mig.}$ (%)														
US	0.998	0.989	0.949	0.834	0.703	0.648	0.635	0.632	0.631	0.631	0.631	0.631	0.631	0.631
Canada	0.002	0.011	0.051	0.166	0.297	0.352	0.365	0.368	0.369	0.369	0.369	0.369	0.369	0.369
$W^{Avg.}$ (kg.)	0.259	0.359	0.460	0.528	0.575	0.618	0.644	0.655	0.652	0.711	0.686	0.729	0.776	0.797
P^{SMF} (%)	0.000	0.500	0.750	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
P^{FW} (%)	0.480	0.501	0.512	0.520	0.524	0.526	0.529	0.536	0.539	0.544	0.553	0.561	0.568	0.575
N^1 (billion fish)		0.148	1.076	0.082	0.420	0.622	0.062	0.000	0.901	0.012	0.006	0.004	0.367	0.149
$B^{Opt.}$ (million mt)	1.0800													
$F^{Opt.}$ (%)	0.2200													
R (billion fish)	0.4060													
M (%)	0.0183													

Source: Dorn, 1995

4.4 The Bioeconomic Model

The bioeconomic model incorporates the biological and harvest equations developed in the previous section with the processing and economic information developed in section 3.3. However, unlike the static model of Chapter 3, processing costs decrease through the harvest season to reflect increasing PRR's experienced by processors through the processing season. In discussions with processors (Tuininga, 1995), individuals were not able to quantify the seasonal variation in PRR's, although processors indicated that PRR's increased in the early season coinciding with decreasing moisture and increasing protein content before leveling out sometime in July. Table 4.3 provides the PRR information by product form used in the model that attempts to reflect the seasonal change in PRR's and how the changing yields impact variable processing costs (as defined in Table 3.3). Larkin (1995) developed equations for estimating surimi and meal yields based on monthly changes in the ratio of weight to length and protein and moisture content which provide similar PRR estimates.

The following equations are used to determine the processing industries' product form portfolio which maximizes net present value given a specific level of risk:

Division of landings into raw product:

$$L_{y,h}^{mt} = \sum_{i=l}^{n} Q_{y,h,i}^{R} \qquad 4.17$$

Finished weight:

$$Q_{y,h,i}^{F} = Q_{y,h,i}^{R} PRR_{h,i} \qquad 4.18$$

Table 4.3 Pacific Whiting Seasonal Processing Estimates

Product Recovery Rates by Month

	Month						
Product Form*	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.
M. Blk.	0.310	0.320	0.330	0.340	0.340	0.340	0.340
Layr. -a	0.210	0.220	0.230	0.240	0.240	0.240	0.240
Layr. -b	0.300	0.310	0.320	0.330	0.330	0.330	0.330
Brd. -b	0.344	0.361	0.377	0.393	0.393	0.393	0.393
Brd. -a	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
Suri.	0.151	0.156	0.161	0.166	0.166	0.166	0.166
Shat. -a	0.210	0.220	0.230	0.240	0.240	0.240	0.240
Shat. -b	0.210	0.220	0.230	0.240	0.240	0.240	0.240
IQF -a	0.210	0.220	0.230	0.240	0.240	0.240	0.240
IQF -b	0.210	0.220	0.230	0.240	0.240	0.240	0.240

Variable Cost of Production of Product Forms (per finished lb.)

	Month						
Product Form*	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.
M. Blk.	0.313	0.308	0.303	0.299	0.299	0.299	0.299
Layr. -a	0.821	0.810	0.800	0.791	0.791	0.791	0.791
Layr. -b	0.723	0.718	0.713	0.708	0.708	0.708	0.708
Brd. -b	0.942	0.935	0.929	0.923	0.923	0.923	0.923
Brd. -a	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
Suri.	0.711	0.700	0.690	0.681	0.681	0.681	0.681
Shat. -a	0.821	0.810	0.800	0.791	0.791	0.791	0.791
Shat. -b	0.821	0.810	0.800	0.791	0.791	0.791	0.791
IQF -a	0.671	0.660	0.650	0.641	0.641	0.641	0.641
IQF -b	0.671	0.660	0.650	0.641	0.641	0.641	0.641

* See Table 3.1 for descriptions.

Production of finished products by year:

$$Q_{y,i}^{F-Y} = \sum_{h} Q_{y,h,i}^{F} \qquad 4.19$$

Portfolio distribution of products:

$$Q_{y,i}^{F-Y} = x_{y,i} Q_{y}^{T} \qquad 4.20$$

$$\sum_{i} Q_{y,i}^{F-Y} = Q_{y}^{T} \qquad 4.21$$

Portfolio risk:

$$\sigma_{y} = \sqrt{\sum_{i=1}^{n} \sum_{j=1}^{n} x_{y,i} x_{y,j} \sigma_{i,j}} \qquad 4.22$$

Proportions of product forms must sum to one and be positive:

$$\sum_{i=1}^{n} x_{y,i} = 1 \qquad 4.23$$

$$x_{y,i} \geq 0 \qquad 4.24$$

Net income of finished products by year:

$$I_{y,i}^{Y} = \sum_{h} Q_{y,h,i}^{F} \cdot \left(P_{i} - VC_{h,i}\right) \qquad 4.25$$

Discounted net income of finished products:

$$I_{i} = \sum_{y} I_{y,i}^{Y} \left(1/1+r\right)^{y} \qquad 4.26$$

Objective Function (Net present value of finished products):

$$NPV = \left(\sum_{i=1}^{n} I_{i}\right) - FC \qquad 4.27$$

For simplicity, it has been assumed that all shore-based processing occurs at one plant that has the capability to process all of the product forms. Some processors do in fact have the equipment necessary to process all of the product forms. However, in many cases market prices are too low or established markets do not exist in sufficient size in order to justify processing. Fixed costs incurred by the processors are included as a lump sum ($15 million) based on an average of the findings of Radtke (1995b) and from finished product form quantities generated by the model and multiplied by the fixed cost estimate of $0.114 (from Table 3.2). Alternatively, fixed costs could be modeled from the perspective that the processing firm does not currently process Pacific whiting and must purchase the necessary processing equipment. In this case, the quantity of equipment required would be dictated by the maximum quantity of fish processed in a month during the harvest season. Although attempted, the required equation necessary to perform this function is not differentiable and thus the current algorithm in the MINOS solver used by GAMS cannot solve for this model specification.

The model allows for the determination of inter and intra-year harvesting rates and product form production that maximize net present value over a three year period given a specified level of risk. A three year period is utilized since it is the frequency in which the NMFS conducts ocean trawl surveys in order to obtain estimates of the size and age distribution of the Pacific whiting biomass (Dorn, 1995). In addition, since the model grows exponentially with an increase in the number of harvest years, the time and resources required for MINOS to solve the highly non-linear model increase exponentially when solving for more than three harvest years.

4.5 Results

The efficient portfolio frontier generated by the bioeconomic portfolio model resembles that which was generated in the static model of section 3.5. However, despite their apparent similarity, there are significant differences in portfolio structures between the alternative models. Most importantly, the dynamic model selects the production of 2-4 oz. IQF fillets rather than increased surimi and H&G production through the middle range of risky portfolios. Portfolio composition generated by the bioeconomic portfolio is provided in Table 4.4 and depicted in Figure 4.1. In constructing the portfolios, total landings remain constant at 473.8 mt over the three year interval. This consistent determination of maximum allowable landings reflects the fact that the amount to harvest (invest) is an independent decision from the amount of expected risk and return a processor (investor) desires based on the alternative portfolio combinations.

Low risk product form portfolios consist primarily of H&G and 4-6 oz. IQF fillets. The product form of lowest risk, raw breaded portions, is utilized in the lowest risk portfolio. However, this portfolio would produce the lowest NPV to processors 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 percent) and is achieved through the production of roughly 69 percent H&G and 30 percent 4-6 oz. IQF fillets. This portfolio has a beta of 0.72, indicating that it is below the average level of risk of processing alternatives. Portfolios of greater risk, while inefficient, consist of IQF fillets, decreasing quantities of

Table 4.4 *I-V* Portfolio Construction of the Baseline Bioeconomic Model

				Product Form Mix (%)											
Portfolio	Risk	NPV	Beta	H&G	Blk.	M. Blk.	Suri	Layr. -a	Layr. -b	Shat. -a	Shat. -b	IQF -a	IQF -b	Brd. -a	Brd. -b
1	0.500	$18.59	2.443				0.983						0.017		
2	0.490	$18.73	2.421				0.958						0.042		
3	0.480	$18.87	2.398				0.933						0.067		
4	0.470	$19.02	2.375				0.907						0.093		
5	0.460	$19.17	2.352				0.882						0.118		
6	0.450	$19.33	2.329				0.856						0.144		
7	0.440	$19.48	2.305				0.830						0.170		
8	0.430	$19.65	2.282				0.804						0.196		
9	0.420	$19.81	2.258				0.778						0.222		
10	0.410	$19.99	2.234				0.751						0.249		
11	0.400	$20.16	2.210				0.724						0.276		
12	0.390	$20.33	2.185				0.696					0.004	0.300		
13	0.380	$20.40	2.158				0.667					0.033	0.300		
14	0.370	$20.47	2.132				0.637					0.063	0.300		
15	0.360	$20.55	2.105				0.606					0.094	0.300		
16	0.350	$20.63	2.077				0.575					0.125	0.300		
17	0.340	$20.71	2.049				0.544					0.156	0.300		
18	0.330	$20.79	2.021				0.512					0.188	0.300		
19	0.320	$20.88	1.992				0.479					0.221	0.300		
20	0.310	$20.97	1.962				0.446					0.254	0.300		
21	0.300	$21.07	1.931				0.411					0.289	0.300		
22	0.290	$21.17	1.900				0.376					0.324	0.300		
23	0.280	$21.28	1.867				0.339					0.361	0.300		
24	0.270	$21.40	1.832				0.300					0.400	0.300		
25	0.260	$21.53	1.795				0.259					0.441	0.300		
26	0.250	$21.68	1.756				0.214					0.486	0.300		
27	0.240	$21.85	1.712				0.165					0.535	0.300		
28	0.230	$22.05	1.661				0.107					0.593	0.300		
29	0.220	$22.33	1.594				0.033					0.667	0.300		
30	0.210	$22.53	1.523	0.035								0.665	0.300		
31	0.200	$22.64	1.460	0.086								0.614	0.300		
32	0.190	$22.76	1.397	0.138								0.562	0.300		
33	0.180	$22.88	1.334	0.190								0.510	0.300		
34	0.170	$23.02	1.270	0.242								0.458	0.300		
35	0.160	$23.16	1.206	0.295								0.405	0.300		
36	0.150	$23.32	1.141	0.384								0.352	0.300		
37	0.140	$23.49	1.075	0.401								0.299	0.300		
38	0.130	$23.68	1.009	0.456								0.244	0.300		
39	0.120	$23.88	0.941	0.512								0.188	0.300		
40	0.110	$24.11	0.872	0.569								0.131	0.300		
41	0.100	$24.38	0.799	0.628								0.072	0.300		
42	0.090	$24.69	0.724	0.690								0.010	0.300		
43	0.080	$24.52	0.651	0.750									0.250		
44	0.070	$24.20	0.569	0.818									0.182		
45	0.060	$23.61	0.447	0.919									0.081		
46	0.050	$21.07	0.412	0.940						0.050			0.010		
47	0.040	$16.53	0.429	0.718	0.067					0.074					0.141

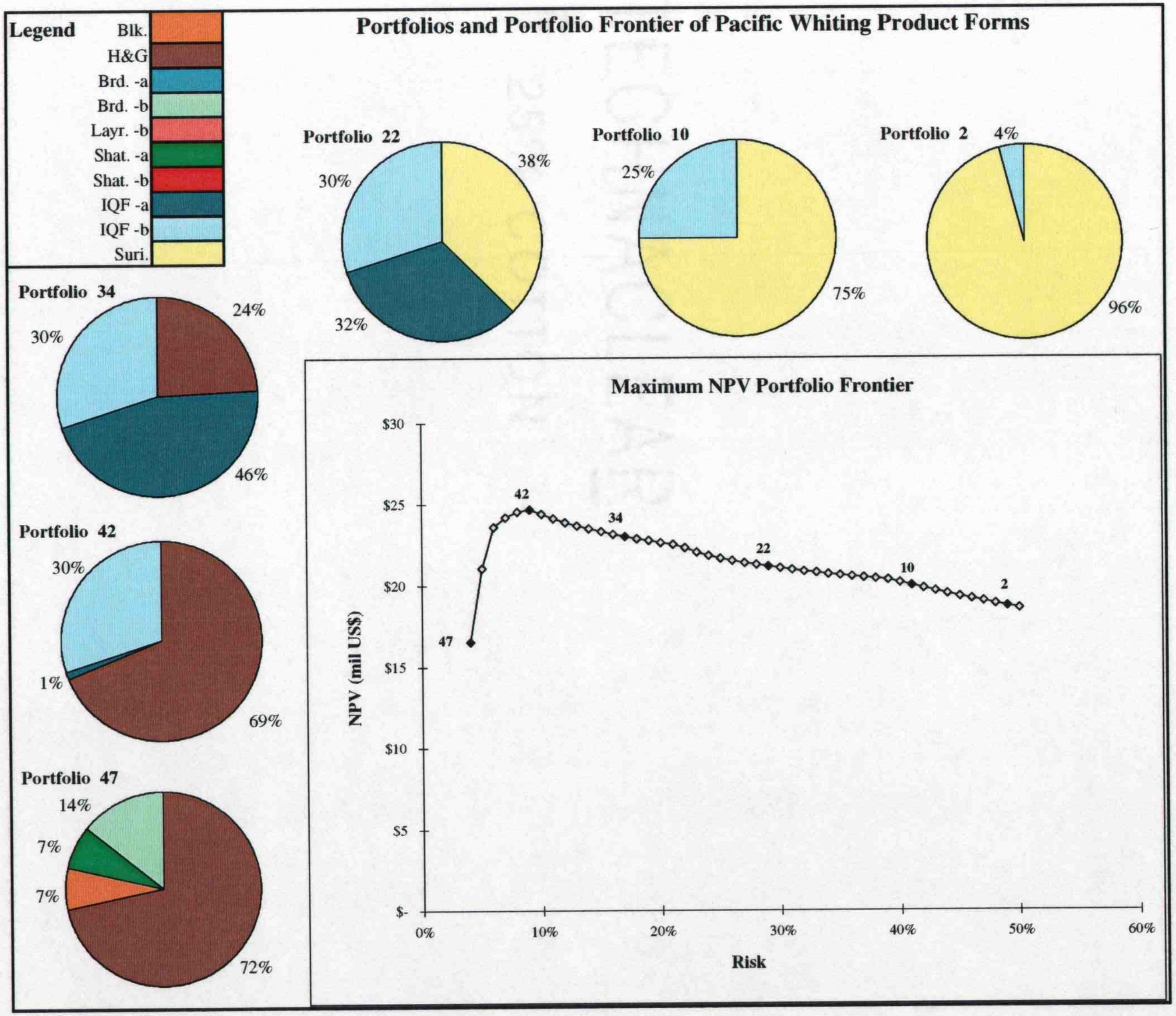


Figure 4.1 Portfolios and *I-V* Portfolio Frontier of the Baseline Bioeconomic Model

H&G, and increasing proportions of surimi. Through the middle range of risk, portfolios contain a maximum of 30 percent 4-6 oz. IQF fillets due to the model constraint as explained in section 3.4. Where this constraint is binding, NPV is maximized through the substitution of 2-4 oz. IQF fillets.

The model chooses to harvest and produce products late in the fishing season (April through October) given onshore processing capacity constraints of 30 thousand mt per month. In all of the portfolio's constructed, no fishing occurs earlier than July. This is due to higher product recovery rates which occur later in the fishing season. Higher product recovery rates cause an increase the quantity of finished product per unit of raw fish landed that ultimately reduces the processing costs per finished pound. In addition, the model maximizes NPV with the production of H&G primarily at the beginning of the processing season while producing IQF fillets towards the end of the processing season. In high risk portfolios consisting of IQF fillets and surimi, NPV is maximized through the production of fillets primarily in the early stages of processing while switching to surimi later in the season. In moving along the portfolio frontier from high to low risk, processing strategies make a transition from surimi to H&G production between risk levels of 21 and 22 percent. The processing of raw breaded portions typically follows the production of H&G in the lowest risk portfolios.

4.6 Sensitivity Analysis and Alternative Scenarios

Sensitivity analysis was performed to determine which of the variables in the bioeconomic portfolio model have the most impact on the value and mix of product forms produced. In twenty-six scenarios, four primary parameters of the model were varied to determine the effects on model results: production constraints, number of harvest years, annual recruitment, and expected prices. The construction of the portfolio frontier through the maximization of NPV over the available range of risk is in itself sensitivity analysis. The fact that the shape of the portfolio frontier is relatively smooth, given the various model constraints, indicates that the model is not providing results from inferior solutions caused by local optima. The following are selected scenarios resulting from the sensitivity analysis.

4.6.1 Constraints On the Production of Product Forms

An additional constraint was added to the bioeconomic portfolio model to reflect the limited market for H&G product. In Figure 4.1 low risk portfolios are dominated by the production of H&G. However, the current market for H&G product is limited and it is not expected that the seafood industry could absorb more than 25 percent of the total finished product from Pacific whiting to be in the form of H&G without expecting a significant decrease in the price. Including this constraint into the model forces other product form proportions to be increased such as IQF fillets, blocks and raw breaded products with less emphasis on H&G and shatterpack fillets in low risk portfolios. Model results for this scenario are provided in Table 4.5 and depicted in Figure 4.2. Using this constraint, a maximum net present value of $23 million is obtained compared to $25 million of the baseline model specification. However, this maximum is achieved at a higher level of risk, 17 percent versus 9 percent in the previous model. The beta of this

Table 4.5 Portfolio Model Results with Constraint on H&G Production

				Product Form Mix (%)											
Portfolio	Risk	NPV	Beta	H&G	Blk.	M. Blk.	Suri	Layr. -a	Layr. -b	Shat. -a	Shat. -b	IQF -a	IQF -b	Brd. -a	Brd. -b
1	0.500	$18.59	2.443				0.983						0.017		
2	0.490	$18.73	2.421				0.958						0.042		
3	0.480	$18.87	2.398				0.933						0.067		
4	0.470	$19.02	2.375				0.907						0.093		
5	0.460	$19.17	2.352				0.882						0.118		
6	0.450	$19.33	2.329				0.856						0.144		
7	0.440	$19.48	2.305				0.830						0.170		
8	0.430	$19.65	2.282				0.804						0.196		
9	0.420	$19.81	2.258				0.778						0.222		
10	0.410	$19.99	2.234				0.751						0.249		
11	0.400	$20.16	2.210				0.724						0.276		
12	0.390	$20.33	2.185				0.696					0.004	0.300		
13	0.380	$20.40	2.158				0.667					0.033	0.300		
14	0.370	$20.47	2.132				0.637					0.063	0.300		
15	0.360	$20.55	2.105				0.606					0.094	0.300		
16	0.350	$20.63	2.077				0.575					0.125	0.300		
17	0.340	$20.71	2.049				0.544					0.156	0.300		
18	0.330	$20.79	2.021				0.512					0.188	0.300		
19	0.320	$20.88	1.992				0.479					0.221	0.300		
20	0.310	$20.97	1.962				0.446					0.254	0.300		
21	0.300	$21.07	1.931				0.411					0.289	0.300		
22	0.290	$21.17	1.900				0.376					0.324	0.300		
23	0.280	$21.28	1.867				0.339					0.361	0.300		
24	0.270	$21.40	1.832				0.300					0.400	0.300		
25	0.260	$21.53	1.795				0.259					0.441	0.300		
26	0.250	$21.68	1.756				0.214					0.486	0.300		
27	0.240	$21.85	1.712				0.165					0.535	0.300		
28	0.230	$22.05	1.661				0.107					0.593	0.300		
29	0.220	$22.33	1.594				0.033					0.667	0.300		
30	0.210	$22.53	1.523	0.035								0.665	0.300		
31	0.200	$22.64	1.460	0.086								0.614	0.300		
32	0.190	$22.76	1.397	0.138								0.562	0.300		
33	0.180	$22.88	1.334	0.190								0.510	0.300		
34	0.170	$23.02	1.270	0.242								0.458	0.300		
35	0.160	$22.71	1.200	0.250								0.380	0.300	0.070	
36	0.150	$22.27	1.125	0.250								0.330	0.300	0.054	0.065
37	0.140	$21.81	1.049	0.250								0.294	0.300		0.156
38	0.130	$21.33	0.973	0.250								0.238	0.300		0.212
39	0.120	$20.81	0.897	0.250								0.182	0.300		0.268
40	0.110	$20.25	0.820	0.250								0.125	0.300		0.325
41	0.100	$19.66	0.790	0.250	0.045							0.087	0.300		0.318
42	0.090	$19.05	0.772	0.250	0.103							0.054	0.300		0.293
43	0.080	$18.43	0.739	0.250	0.151							0.013	0.300		0.286
44	0.070	$17.63	0.752	0.250	0.258								0.285		0.207
45	0.060	$16.60	0.675	0.250	0.255								0.229		0.266
46	0.050	$15.41	0.586	0.250	0.240								0.167		0.343
47	0.040	$13.93	0.477	0.250	0.210								0.096		0.443

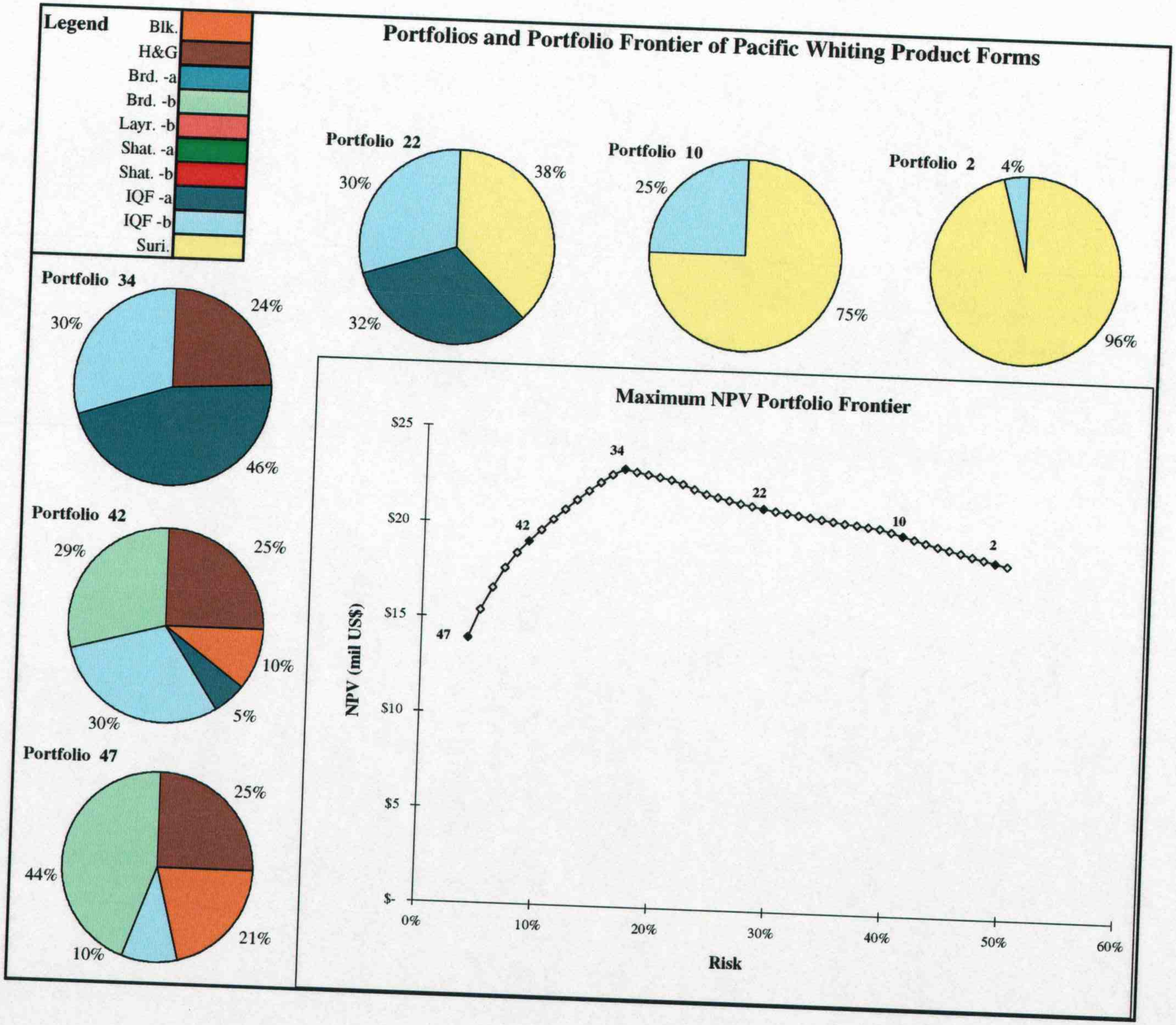


Figure 4.2 Portfolio Model Results with Constraint on H&G Production

portfolio is 1.27, indicating that the risk associated with this portfolio mix is greater than the average of the product forms.

4.6.2 Changes in Recruitment and in Total Years of Production

Using the model specification in Section 4.6.1, the bioeconomic portfolio model was solved using alternative recruitment rates and harvest years. While this caused variation in the quantity of Pacific whiting harvested, the structure of the portfolio frontier remained unchanged. For instance, when the recruitment rate was increased from the median of 1972-94 (0.406 billion age two fish) to the median of 1960-94 (0.893 billion age two fish), as estimated by Dorn (1995), total US onshore catch increased from 476.8 to 524.4 mt. However the mix of product forms in the portfolio's remained the same for each level of risk, the only change in the portfolio frontier was in its upward shift. An additional upward shift results from increasing the number of harvest seasons modeled from three to six. In this scenario, total US onshore catch increased an additional 297.7 mt. from 524.4 to 822.1 mt. Similarly, utilizing alternative recruitment specifications in the model such as varying high and low annual recruitment did not impact the structure of the portfolio frontier.

4.6.3 Changes in Product Form Prices

The mix of product forms in portfolios and ultimately the construction of portfolio frontiers are sensitive to the changes in the prices of the alternative products. Using the model developed in Section 4.6.1, which limited the portfolio proportions of H&G to 25 percent and 4-6 oz. fillets to 30 percent, prices were varied for the three primary product forms: H&G, fillets, and surimi. An increase in the price of H&G by $0.05 increased the proportion of H&G and surimi while reducing the proportion of 2-4 oz. IQF fillets in portfolios of the middle range of risk. If, instead, the price of all fillets is decreased by $0.10, fillet production is eliminated from all portfolios. In this scenario, greater proportions of H&G, surimi, and cooked breaded portions are used in efficient portfolios. Alternatively, if the price of surimi is increased by $0.10, the proportions of H&G, surimi, and raw breaded portions are increased in portfolios of the middle range of risk while the proportions of 2-4 oz. IQF fillets are decreased. Results of this scenario are provided in Table 4.6 and Figure 4.3. The range of efficient portfolios, those portfolios on the positively sloped portion of the frontier, is extended to a higher level of risk, 40 percent compared to 17 percent from the model specified in Section 4.6.1. NPV is maximized at $30.7 million in portfolio 11 which consists of 72 percent surimi and 28 percent 4-6 oz. IQF fillets (assuming an annual recruitment of 0.893 billion age two fish).

The product recovery rates used in the model are additional parameters which could potentially impact the construction of portfolios and timing of optimal harvests. However, since there does not appear to be substantial inter-year variation in product recovery rates and it is expected that the rates among the alternative product forms would move together, sensitivity analysis on these parameters would not likely provide a significant amount of additional information.

Through sensitivity analysis of the bioeconomic portfolio model, a pattern emerged for the order of the production of product forms during the processing season. This pattern consisted of the production of H&G early in the processing season followed

Table 4.6 Portfolio Model Results with an Increase in Surimi Price

				Product Form Mix (%)											
Portfolio	Risk	NPV	Beta	H&G	Blk.	M. Blk.	Suri	Layr. -a	Layr. -b	Shat. -a	Shat. -b	IQF -a	IQF -b	Brd. -a	Brd. -b
1	0.500	$30.73	2.443				0.983						0.017		
2	0.490	$30.73	2.421				0.958						0.042		
3	0.480	$30.73	2.398				0.933						0.067		
4	0.470	$30.73	2.375				0.907						0.093		
5	0.460	$30.73	2.352				0.882						0.118		
6	0.450	$30.73	2.329				0.856						0.144		
7	0.440	$30.73	2.305				0.830						0.170		
8	0.430	$30.73	2.282				0.804						0.196		
9	0.420	$30.73	2.258				0.778						0.222		
10	0.410	$30.73	2.234				0.751						0.249		
11	0.400	$30.73	2.210				0.724						0.276		
12	0.390	$30.73	2.183	0.003			0.679						0.300		
13	0.380	$30.70	2.140	0.023			0.677						0.300		
14	0.370	$30.67	2.098	0.043			0.657						0.300		
15	0.360	$30.65	2.056	0.063			0.637						0.300		
16	0.350	$30.62	2.013	0.083			0.617						0.300		
17	0.340	$30.59	1.971	0.103			0.597						0.300		
18	0.330	$30.56	1.928	0.123			0.577						0.300		
19	0.320	$30.53	1.886	0.143			0.557						0.300		
20	0.310	$30.49	1.843	0.163			0.537						0.300		
21	0.300	$30.46	1.800	0.184			0.516						0.300		
22	0.290	$30.42	1.757	0.204			0.496						0.300		
23	0.280	$30.38	1.714	0.225			0.475						0.300		
24	0.270	$30.35	1.671	0.245			0.455						0.300		
25	0.260	$30.19	1.639	0.250			0.426					0.024	0.300		
26	0.250	$29.98	1.610	0.250			0.393					0.057	0.300		
27	0.240	$29.76	1.580	0.250			0.359					0.091	0.300		
28	0.230	$29.52	1.549	0.250			0.324					0.126	0.300		
29	0.220	$29.27	1.515	0.250			0.289					0.157	0.300	0.004	
30	0.210	$28.99	1.464	0.250			0.271					0.136	0.300	0.043	
31	0.200	$28.70	1.412	0.250			0.253					0.112	0.300	0.085	
32	0.190	$28.38	1.358	0.250			0.235					0.086	0.300	0.129	
33	0.180	$28.03	1.302	0.250			0.217					0.057	0.300	0.175	
34	0.170	$27.65	1.243	0.250			0.199					0.025	0.300	0.225	
35	0.160	$27.21	1.183	0.250			0.178						0.300	0.272	
36	0.150	$26.72	1.119	0.250			0.154						0.300	0.251	0.045
37	0.140	$26.19	1.047	0.250			0.141						0.300	0.166	0.143
38	0.130	$25.64	0.975	0.250			0.126						0.300	0.083	0.241
39	0.120	$25.06	0.901	0.250			0.111						0.300		0.338
40	0.110	$24.42	0.847	0.250	0.012		0.085						0.300		0.353
41	0.100	$23.73	0.861	0.250	0.095		0.074						0.300		0.281
42	0.090	$23.00	0.862	0.250	0.174		0.058						0.300		0.218
43	0.080	$22.15	0.847	0.250	0.250		0.035						0.300		0.164
44	0.070	$21.13	0.781	0.250	0.262		0.031						0.254		0.203
45	0.060	$19.99	0.702	0.250	0.258		0.028						0.201		0.263
46	0.050	$18.69	0.609	0.250	0.243		0.024						0.144		0.339
47	0.040	$17.07	0.469	0.250	0.213		0.019						0.078		0.440

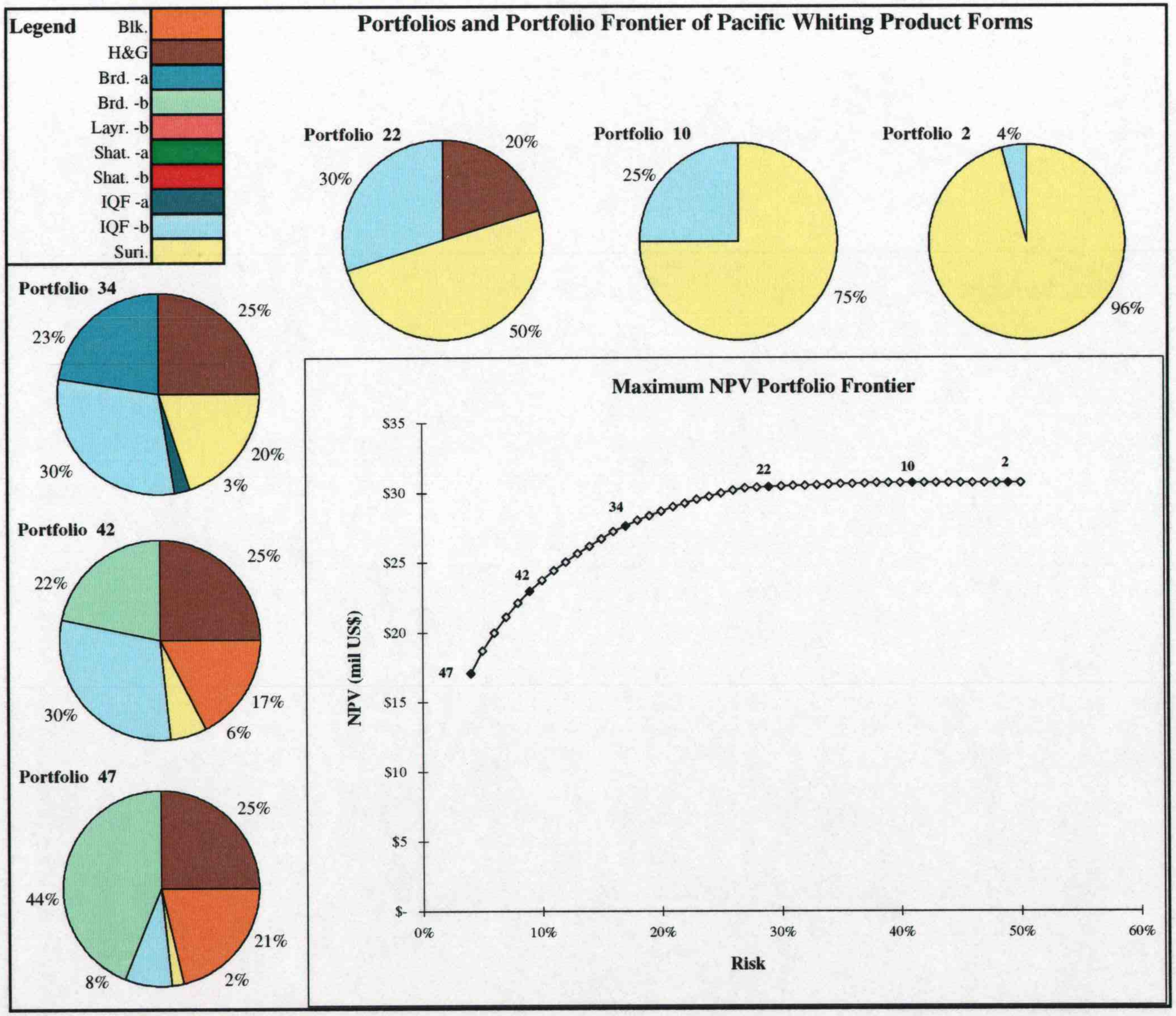


Figure 4.3 Portfolio Model Results with an Increase in Surimi Price

by breaded portions, blocks, and fillets, respectively. The model typically chose the production of surimi after all other product forms had been produced. This resulting pattern undoubtedly reflects the seasonal change in product recovery rates which affect net income per pound of finished product. Table 4.7 provides examples of processing patterns, in percent distribution of finished weight by month, from selected portfolios generated by the model. For reference purposes, portfolio mix is also provided for each example. These results are based on the model containing the constraint that limits the production of H&G to 25 percent of total production (Table 4.5). In portfolio 22, the majority of fillet production occurs before surimi processing. In portfolio 34, H&G is produced earlier in the processing season than fillets. Results of portfolios 42 and 47 show that in maximizing net income, the processing of breaded products and blocks occurs between the production of H&G and fillets. These relationships, in conjunction with the patterns resulting from the other portfolios generated through the sensitivity analysis, are the basis for the overall production pattern discussed previously. Table 4.7 also shows that the model does not choose to harvest in the months of April, May and June. In fact, net income is maximized by the model through processing as late in the season as possible, given the processing constraint. Since the seasonal variation in product recovery rates was estimated based on discussions with processors, further refinement of these parameter estimates is necessary in order to be able to confirm the pattern of processing selected by the model.

Table 4.7 Distributions of Intra-Seasonal Processing

Portfolio 22

	Product Form			
Month	Suri	IQF -a	IQF -b	**Total**
July	0.0%	0.0%	45.8%	13.8%
Aug.	3.5%	73.2%	3.9%	26.2%
Sept.	49.8%	24.1%	18.9%	32.2%
Oct.	46.8%	2.7%	31.3%	27.9%
Total	100.0%	100.0%	100.0%	100.0%
Portfolio Mix	**37.6%**	**32.4%**	**30.0%**	100.0%

Portfolio 34

	Product Form			
Month	H&G	IQF -a	IQF -b	**Total**
July	49.8%	0.0%	16.1%	16.9%
Aug.	31.2%	9.2%	41.0%	24.0%
Sept.	19.0%	48.7%	18.9%	32.6%
Oct.	0.0%	42.1%	23.9%	26.5%
Total	100.0%	100.0%	100.0%	100.0%
Portfolio Mix	**24.2%**	**45.8%**	**30.0%**	100.0%

Portfolio 42

	Product Form					
Month	Brd. -b	H&G	Blk.	IQF -a	IQF -b	**Total**
July	0.0%	49.8%	31.6%	0.0%	0.0%	15.7%
Aug.	65.9%	31.2%	18.2%	0.0%	0.0%	29.0%
Sept.	34.1%	19.0%	31.2%	31.2%	42.7%	32.5%
Oct.	0.0%	0.0%	19.0%	68.8%	57.3%	22.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Portfolio Mix	**29.3%**	**25.0%**	**10.3%**	**5.4%**	**30.0%**	100.0%

Portfolio 47

	Product Form				
Month	Brd. -b	H&G	Blk.	IQF -b	**Total**
July	0.0%	49.8%	12.3%	0.0%	15.0%
Aug.	13.3%	31.2%	37.5%	8.6%	22.4%
Sept.	66.2%	19.0%	18.5%	0.0%	38.0%
Oct.	20.5%	0.0%	31.8%	91.4%	24.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Portfolio Mix	**44.3%**	**25.0%**	**21.0%**	**9.6%**	100.0%

4.7 Conclusion

Similar to the results of the portfolio model developed in section 3.5, portfolios and portfolio frontiers generated by the bioeconomic portfolio model throughout the sensitivity analysis were dominated by H&G, IQF fillets and surimi in addition to raw breaded portions in low risk portfolios. However, as indicated in the previous section, portfolio mix is sensitive to product form prices. In the case of surimi prices, which have been historically volatile relative to the prices of other product forms, this magnifies the importance of having accurate market data in the model. Furthermore, if all processors changed their production practices and, for example, increased the supply of H&G on the market, prices would likely decrease due to the high substitutability of identical products from other species.

The integration of the bioeconomic and portfolio models provides a wealth of information to Pacific whiting processors. The model can assist processors in determining optimal portfolios of product forms to produce, the timing of the harvests given changing product recovery rates, and the intra-season processing strategies in order to maximize their profits. Furthermore, the maximization of profits is done within the risk preference of the individual processor.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary and Conclusions

The primary objective of this thesis was to explore potential opportunities for seafood processors to increase profits and/or reduce risk through the diversification of product forms from a single species of fish. A secondary objective was to determine possible intra-seasonal processing strategies that would occur as a result of achieving the primary objective. Bioeconomic portfolio models were developed to generate portfolio frontiers to determine the trade-off between risk and expected return or expected net income for various combinations of alternative seafood product forms. These models, through maximizing net income, also determined inter and intra-seasonal harvest and processing levels given biological and processor constraints.

Chapter 2 introduced the application of portfolio analysis to seafood processing based on its origination in the finance literature and its applications in farm management. A method was proposed for constructing portfolios and portfolio frontiers when there are undeveloped markets or incomplete information exists.

Chapter 3 applied the theory and methods developed in the second chapter to the seafood processing industry. The Pacific whiting fishery was used as a case study in which to show the potential gains of product form diversification from a single species. In this static representation of the fishery, the analysis shows the long run profitability and risk associated with processing individual product forms and portfolios.

In Chapter 4, the portfolio model was integrated with a multi-year seasonal bioeconomic model of the Pacific whiting fishery in order to determine optimal portfolios of product forms. The dynamic model incorporated yearly variation in stock recruitment in addition to seasonal variation in the size and intrinsic qualities of the fish. Modeling seasonal variation provided a means of determining intra-seasonal processing strategies.

Based on the analysis conducted, it appears that Pacific whiting processors may be able to better position themselves to maximize the NPV of the harvest while reducing some of risk inherent in seafood markets by changing the mix of product forms they produce. However, in the majority of portfolios constructed by the models, three to four product forms tend to dominate the portfolios. This leads to the conclusion that increased diversification of greater than three to four product forms may not be economically efficient. While the current portfolio of product forms produced by Pacific whiting processors may not be completely efficient, it may reflect their risk preferences and/or their expectations on future markets and prices for their products.

5.2 Future Research

While the application of portfolio analysis to seafood processing appears to be a useful tool for developing future processing and fisheries management strategies, obtaining more complete information concerning market prices, processing costs, and intra-seasonal changes in the processing characteristics of the species would provide a better foundation on which to base portfolio analysis. In addition, allocations and utilization by nations and fishing sectors need to be explored for differences in available product form choices and processing technologies as a result of temporal and spatial variability of the species due to migratory patterns. The estimation of demand curves for each of the product forms would also be an important extension of this research. This would create product forms prices that are endogenous rather the exogenous variables of the model that would ultimately impact product form selection. Finally, the modeling of fixed costs, such as processing machinery, would allow for the estimation of costs associated with developing capabilities for processing alternative product forms. As discussed in Section 4.4, the GAMS software package did not have the capability to solve the necessary equations at the time on this research.

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APPENDICES

Appendix A

The *E-V* Portfolio Model in Computer Code

The *E-V* Portfolio model of Chapter 3 in GAMS language is reprinted below.

```
* Non-linear Programming Model for Constructing Efficient Portfolio
* Frontiers Using Full-covariance Methodology for
* Pacific Whiting Product Forms
* Developed by Chris Tuininga
* Dept. of Agricultural and Resource Economics
* Oregon State University

$TITLE  A quadratic programming model for PW f-c portfolio analysis
$OFFUPPER OFFUELLIST OFFUELXREF OFFSYMLIST OFFSYMXREF

Set PORTFOLIO /1*51/;

Parameter SEQ(PORTFOLIO)    /1  0.36 /  ;

Set TAR

    / T_RTRN   Target mean annual return on portfolio (%) / ;

Parameter TARGET(TAR)

    / T_RTRN  0.36  /;

Set FORM Product forms produced from cod pollock and whiting
        /
          PLMBAA     M. Blk.
          WTFLAA     Layr. -a
          WTFLBA     Layr. -b
          WTBPRAA    Brd. -b
          WTBPCAA    Brd. -a
          WTHGBB     H&G
          WTBLAB     Blk.
          PLSFAAB    Suri.
          PLFSAB     Shat. -a
          PLFSBB     Shat. -b
          PLFIAB     IQF -a
          PLFIBB     IQF -b  / ;

Alias (FORM,FORMb);

Parameter PRDRET(FORM)

     /    PLMBAA     0.031
          WTFLAA     0.041
          WTFLBA     0.082
          WTBPRAA    0.007
          WTBPCAA    0.025
          WTHGBB     0.087
          WTBLAB     0.130
          PLSFAAB    0.368
          PLFSAB     0.205
          PLFSBB     0.260
          PLFIAB     0.245
          PLFIBB     0.311 / ;
```

```
Parameter BETA(FORM)

     /    PLMBAA     2.279
          WTFLAA     0.307
          WTFLBA     0.247
          WTBPRAA    0.215
          WTBPCAA    0.703
          WTHGBB     0.349
          WTBLAB     0.684
          PLSFAAB    2.459
          PLFSAB     1.383
          PLFSBB     1.523
          PLFIAB     1.569
          PLFIBB     1.557   / ;


Table VCMTRX(FORM,FORMb) Variance-Covariance Matrix

                  PLMBAA           WTFLAA           WTFLBA           WTBPRAA

PLMBAA        0.1151680245     0.0067340366     0.0086850529     0.0063291237
WTFLAA        0.0067340366     0.0043997275     0.0036906089     0.0006878950
WTFLBA        0.0086850529     0.0036906089     0.0051726471     0.0002952841
WTBPRAA       0.0063291237     0.0006878950     0.0002952841     0.0012088794
WTBPCAA       0.0105834485     0.0008364081     -.0005889956     0.0034449746
WTHGBB        0.0078047416     0.0015188453     0.0005572721     0.0013226257
WTBLAB        -.0033908835     0.0009720110     0.0008306352     -.0021257665
PLSFAAB       0.1384984144     0.0063375414     0.0174181648     0.0062740209
PLFSAB        0.0252687036     0.0027703809     0.0037432356     -.0003259205
PLFSBB        0.0225519196     0.0059410895     0.0040985844     0.0034277357
PLFIAB        0.0560131211     0.0062602620     0.0055072108     0.0055718656
PLFIBB        0.0415135577     0.0047396376     0.0025845672     0.0062874535

   +              WTBPCAA          WTHGBB           WTBLAB           PLSFAAB

PLMBAA        0.0105834485     0.0078047416     -.0033908835     0.1384984144
WTFLAA        0.0008364081     0.0015188453     0.0009720110     0.0063375414
WTFLBA        -.0005889956     0.0005572721     0.0008306352     0.0174181648
WTBPRAA       0.0034449746     0.0013226257     -.0021257665     0.0062740209
WTBPCAA       0.0151608112     0.0018314665     -.0072496319     0.0113986867
WTHGBB        0.0018314665     0.0033529451     -.0003378560     -.0013552383
WTBLAB        -.0072496319     -.0003378560     0.0136313883     -.0157633655
PLSFAAB       0.0113986867     -.0013552383     -.0157633655     0.2569323205
PLFSAB        0.0059378655     -.0076450876     0.0038723884     0.0628268564
PLFSBB        0.0187731388     -.0026796720     -.0039533360     0.0467572207
PLFIAB        0.0159184277     0.0042043389     -.0089156544     0.0700357991
PLFIBB        0.0234376091     0.0026808441     -.0123579495     0.0527180718


   +              PLFSAB           PLFSBB           PLFIAB           PLFIBB

PLMBAA        0.0252687036     0.0225519196     0.0560131211     0.0415135577
WTFLAA        0.0027703809     0.0059410895     0.0062602620     0.0047396376
WTFLBA        0.0037432356     0.0040985844     0.0055072108     0.0025845672
WTBPRAA       -.0003259205     0.0034277357     0.0055718656     0.0062874535
WTBPCAA       0.0059378655     0.0187731388     0.0159184277     0.0234376091
WTHGBB        -.0076450876     -.0026796720     0.0042043389     0.0026808441
WTBLAB        0.0038723884     -.0039533360     -.0089156544     -.0123579495
PLSFAAB       0.0628268564     0.0467572207     0.0700357991     0.0527180718
PLFSAB        0.0680418821     0.0518405872     0.0190453404     0.0255901158
PLFSBB        0.0518405872     0.0656825267     0.0308781435     0.0434472778
PLFIAB        0.0190453404     0.0308781435     0.0462438498     0.0459547204
PLFIBB        0.0255901158     0.0434472778     0.0459547204     0.0561151005
;

Variables

     FRAC(FORM)   Fraction of Product Form in Portfolio
     P_VAR        Portfolio Variance
     P_RTRN       Portfolio Return
     RISK         Portfolio Risk
     P_BETA       Portfolio Beta    ;

Positive Variable FRAC, P_VAR ;
```

```
Equations

        E1      Constraint that fractions sum to one
        E2      Calculation of mean return on portfolio
        E3      Constraint on portfolio return
        E4      Calculation of portfolio variance
        E5      Calculation of risk
        E6      Calculation of beta of portfolio ;


     E1..    SUM(FORM, FRAC(FORM)) =E= 1.0 ;

     E2..    SUM(FORM, PRDRET(FORM)* FRAC(FORM)) =E= P_RTRN ;

     E3..    P_RTRN =E= TARGET("T_RTRN") ;

     E4..    SUM((FORM,FORMb),FRAC(FORM)
                   *VCMTRX(FORM,FORMb)*FRAC(FORMb)) =E= P_VAR ;

     E5..    SQRT(P_VAR) =E= RISK ;

     E6..    P_BETA =E= SUM(FORM,FRAC(FORM)*BETA(FORM)) ;

Scalar  COUNT  / 0 /;

Model wtp /All/ ;

   Loop(PORTFOLIO, TARGET("T_RTRN") = SEQ(PORTFOLIO) ;
        SEQ(PORTFOLIO+1) = SEQ(PORTFOLIO)-0.007 ;

   Option SOLPRINT=OFF, LIMROW=0, LIMCOL=0 ;

   COUNT=COUNT+1;

Solve wtp Using NLP Minimizing RISK ;
```

Appendix B

The Bioeconomic Portfolio Model in Computer Code

The baseline Bioeconomic Portfolio model of Chapter 4 in GAMS language is reprinted below.

```
* Non-linear Programming Model for Determining Optimal Catch of
* Pacific Whiting over a Three Year Period
* and Portfolio Diversification of Product Forms
* Developed by Chris Tuininga
* Dept. of Agricultural and Resource Economics
* Oregon State University

$TITLE  A quadratic programming model for PW f-c portfolio analysis
$OFFUPPER OFFUELLIST OFFUELXREF OFFSYMLIST OFFSYMXREF SINGLE

**********  BIOLOGICAL AND HARVEST SECTION

Set    Y          years            / 1994*1996  /
       YFIRST(Y)  first year;
       YFIRST(Y)  = YES$(ORD(Y) EQ 1);

Set    M          months
                  /JAN,FEB,MAR,APR,MAY,JUN,JLY,AUG,SEP,OCT,NOV,DEC/
       MFIRST(M)  first month;
       MFIRST(M)  = YES$(ORD(M) EQ 1);

Set    HAR(M)   harvest months   /APR,MAY,JUN,JLY,AUG,SEP,OCT/;

Set    A          ages             / 2*15    /
       AFIRST(A)  age at recruitment
       ALAST(A)   maximum age;
       AFIRST(A)  = YES$(ORD(A) EQ 1);
       ALAST(A)   = YES$(ORD(A) EQ CARD(A));

Set       C         countries       /   US, CAN    /
          S         sector          /   ON, OFF    /;

Scalars  M_         natural inst. mortality rate monthly   / 0.01883 /
         B_S_OPT    optimal spawning biomass (mil mt)      / 1.080   /
         F_OPT      optimal fishing mortality (low)        / 0.220   /

TABLE   SLCT(A,C,S) selectivities of individual fish at age
            US.ON     US.OFF   CAN.(ON, OFF)
        2   0.18      0.07     0.38
        3   0.40      0.31     0.43
        4   0.67      0.72     0.48
        5   0.86      0.94     0.55
        6   0.95      0.99     0.61
        7   0.98      1.00     0.69
        8   1.00      1.00     0.77
        9   1.00      0.99     0.86
       10   1.00      0.98     0.95
       11   0.98      0.94     1.00
       12   0.91      0.85     0.93
       13   0.75      0.66     0.71
       14   0.45      0.41     0.41
       15   0.19      0.20     0.19;
```

```
Table  P_MIG(A,C) proportion of fish migrating to each country
             US          CAN
       2   0.998        0.002
       3   0.989        0.011
       4   0.949        0.051
       5   0.834        0.166
       6   0.703        0.297
       7   0.648        0.352
       8   0.635        0.365
       9   0.632        0.368
      10   0.631        0.369
      11   0.631        0.369
      12   0.631        0.369
      13   0.631        0.369
      14   0.631        0.369
      15   0.631        0.369  ;


Parameter AV_W(A) mean weight of fish in kg.
    /  2  0.259
       3  0.359
       4  0.460
       5  0.528
       6  0.575
       7  0.618
       8  0.644
       9  0.655
      10  0.652
      11  0.711
      12  0.686
      13  0.729
      14  0.776
      15  0.797   /;

Set  GAIN    form of weight gain /CONST, LIN, QUAD, LN/;

Table SLOPE(A,GAIN)   estimated slopes in weight gain equations
        CONST     LIN      QUAD       LN
    2   0.211   0.0217  -0.0017     0.0
    3   0.310  -0.0189   0.0        0.1093
    4   0.379   0.0330  -0.00075    0.0
    5   0.446   0.0458   0.0       -0.0729
    6   0.481  -0.0035   0.0027     0.0
    7   0.504  -0.0104   0.0        0.0814
    8   0.523   0.0330   0.0        0.0
    9   0.537   0.0222   0.0        0.0
   10   0.575  -0.0370   0.006      0.0
   11   0.622   0.0      0.0        0.0
   12   0.721   0.0      0.0        0.0
   13   0.752   0.117   -0.0184     0.0
   14   0.805   0.117   -0.0184     0.0
   15   0.837   0.117   -0.0184     0.0;

Parameter PSMF(A) proportion of sexually mature females
    /  2  0.0
       3  0.5
       4  0.75
       5  1.0
       6  1.0
       7  1.0
       8  1.0
       9  1.0
      10  1.0
      11  1.0
      12  1.0
      13  1.0
      14  1.0
      15  1.0     /;
```

```
Parameter PFW(A) proportion of females by weight kg
    /  2  0.480
       3  0.501
       4  0.512
       5  0.520
       6  0.524
       7  0.526
       8  0.529
       9  0.536
      10  0.539
      11  0.544
      12  0.553
      13  0.561
      14  0.568
      15  0.575 /;

Parameter N_t0(A) billions of fish in initial year

   /   3  0.148
       4  1.076
       5  0.082
       6  0.420
       7  0.622
       8  0.062
       9  0.000
      10  0.901
      11  0.012
      12  0.006
      13  0.004
      14  0.367
      15  0.149  /;

Parameter REC(Y) billions of fish recruited in January

          /  (1994*1996)    0.406  / ;

Positive Variables
     N(Y,M,A)          billions of fish
     A_A(Y,M,A,C)      numbers of fish in oldest age class (bil)
     B_S(Y)            spawning biomass (mil mt)
     F(M,Y,A,C,S)      fishing mortality rate
     Z(M,Y,A,C)        total mortality rate
     FM(Y)             fishing mortality rate
     W(A,M)            seasonal change in weight
     C_(M,Y,A,C,S)     catch (mil fish)
     C_C(C,Y,M,S)      catch (mil fish)
     C_Y(Y,S,C)        catch (mil fish)
     C_MT(Y,M,S)       catch (thous mt)
     C_Y_MT(Y)         catch (thous mt)
     C_S_MT(Y,S)       catch (thous mt)
     S_M(Y,M,S)        allocation by sector and month
     ASF(S)            allocation by sector in F equation
     ASC(S)            allocation by sector
     C_US_MT           US catch (thous mt);

Equations
     E1(M,Y,A)         recruitment of age two fish
     E2(M,Y,A)         initial numbers for each cohort
     E3(M,Y,A)         calc of monthly numbers for each cohort
     E4(M,Y,A)         cohort entering next age class
     E5(Y,M,A,C)       calc of oldest cohort numbers
     E6(M,Y,A,C)       calc of total mortality (monthly)
     E7(M,Y,A,C,S)     fishing mortality based on selectivities
     E8(Y)             fishing mortality as fn of biomass
     E9(Y)             calc of spawning biomass
     E10               allocation by sector (constraint)
     E11               allocation by sector (constraint)
     E12(Y,S)          allocation by sector and month (constraint)
     E13(M,Y,A,C,S)    calc of catch (mil fish)
     E14(C,Y,M,S)      calc of catch by country (mil fish)
     E15(Y,S,C)        calc of catch (mil fish)
     E16(A,M)          calc of fish weight
     E17(Y,M,C,S)      calc of catch (thous mt)
     E18(Y,S)          calc of catch (thous mt)
```

```
     E19(Y)              calc of catch (thous mt)
     E20(Y,S)            calc of catch (thous mt)
     E21                 calc of total fish caught (thous mt) ;

E1(MFIRST,Y,AFIRST)..      N(Y,MFIRST,AFIRST) =E= REC(Y);

E2(MFIRST,YFIRST,A+1)..   N(YFIRST,MFIRST,A+1) =E= N_t0(A+1);

E3(M+1,Y,A)..   N(Y,M+1,A) =E= SUM(C,P_MIG(A,C)*N(Y,M,A)*EXP(-Z(M,Y,A,C)));

E4(MFIRST,Y+1,A+1)..    N(Y+1,MFIRST,A+1) =E= SUM(C,N(Y,"DEC",A)*P_MIG(A,C)
         *EXP(-Z("DEC",Y,A,C))+A_A(Y+1,MFIRST,A+1,C)$(ORD(A)+1 EQ CARD(A)));

E5(Y+1,MFIRST,ALAST,C)..    A_A(Y+1,MFIRST,ALAST,C) =E=
                    EXP(-Z("DEC",Y,ALAST,C))*N(Y,"DEC",ALAST)*  P_MIG(ALAST,C);

E6(M,Y,A,C)..    Z(M,Y,A,C)  =E= M_+SUM(S,F(M,Y,A,C,S));

E7(M,Y,A,C,S)$(HAR(M))..   F(M,Y,A,C,S)$(HAR(M)) =E=
                           FM(Y)*SLCT(A,C,S)*S_M(Y,M,S)*ASF(S);

E8(Y)..          FM(Y) =E= F_OPT*(B_S(Y)/B_S_OPT) ;

E9(Y)..          B_S(Y) =E= SUM(A,N(Y,"JAN",A)*PSMF(A)*PFW(A)*AV_W(A));

E10..            SUM(S,ASF(S)) =E= 1 ;

E11..            SUM(S,ASC(S)) =E= 1 ;

E12(Y,S)..       SUM(M,S_M(Y,M,S)) =E= 1 ;

E13(M,Y,A,C,S)$(HAR(M))..    C_(M,Y,A,C,S)$(HAR(M)) =E=
      (F(M,Y,A,C,S)/Z(M,Y,A,C))*N(Y,M,A)*(1-EXP(-Z(M,Y,A,C)))*P_MIG(A,C)*1000;

E14(C,Y,M,S)$(HAR(M))..   C_C(C,Y,M,S)$(HAR(M))=E=SUM(A,C_(M,Y,A,C,S));

E15(Y,S,C)..     C_Y(Y,S,C) =E= SUM((A,M),C_(M,Y,A,C,S));

E16(A,M)$(HAR(M))..   W(A,M)$(HAR(M)) =E= SLOPE(A,"CONST")
              +SLOPE(A,"LIN")*(ORD(M)-3)  +SLOPE(A,"QUAD")*((ORD(M)-3)**2)
              +SLOPE(A,"LN")*(LOG(ORD(M)-3));

E17(Y,M,C,S)$(HAR(M))..     C_MT(Y,M,S)$(HAR(M)) =E=
                                SUM(A,C_(M,Y,A,"US",S)*W(A,M)); .

E18(Y,S)..     SUM(M,C_MT(Y,M,S)) =E= C_Y_MT(Y)*ASC(S);

E19(Y)..       C_Y_MT(Y) =E= SUM((M,S),C_MT(Y,M,S));

E20(Y,S)..     C_S_MT(Y,S) =E= SUM(M,C_MT(Y,M,S));

E21..          C_US_MT =E= SUM((Y,M,S),C_MT(Y,M,S));

    Z.LO(M,Y,A,C) =       M_   ;
    B_S.LO(Y) =           0.623;

       S_M.FX(Y,M,S)$(ORD(M) LT 4 OR ORD(M) GT 10)=0;
    C_.FX(M,Y,A,C,S)$(ORD(M) LT 4 OR ORD(M) GT 10)=0;
     C_C.FX(C,Y,M,S)$(ORD(M) LT 4 OR ORD(M) GT 10)=0;
     F.FX(M,Y,A,C,S)$(ORD(M) LT 4 OR ORD(M) GT 10)=0;

************* PRODUCT FORM PORTFOLIO SECTION

Set TAR

    / T_RISK   Target mean annual return on portfolio (%) / ;

Parameter TARGET(TAR)

    / T_RISK  0.5  /;
```

```
Set FORM Product forms produced from cod pollock and whiting
       /
          PLMBAA     Pollock Minced Blocks   4x16.5
          WTFLAA     Whiting S.A. Fillets Layerpack Skinless 10 lb.
          WTFLBA     Whiting S.A. Fillets Layerpack Skin-on 10 lb.
          WTBPRAA    Whiting S.A. Breaded Portions Raw 2-4 oz.
          WTBPCAA    Whiting S.A. Breaded Portions Cooked 2-4 oz.
          WTHGBB     Whiting S.A. H&G  5 lb.
          WTBLAB     Whiting S.A. Blocks 4x16.5
          PLSFAAB    Pollock Alaskan Surimi FA Grade
          PLFSAB     Pollock Shat. Fillets 2-4 oz 3x15
          PLFSBB     Pollock Shat. Fillets 4-6 oz 3x15
          PLFIAB     Pollock IQF Fillets   2-4 oz.
          PLFIBB     Pollock IQF Fillets   4-6 oz. / ;

Alias (FORM,FORMb);

Parameter BETA(FORM)

      /
          PLMBAA     2.2792
          WTFLAA     0.3071
          WTFLBA     0.2467
          WTBPRAA    0.2151
          WTBPCAA    0.7033
          WTHGBB     0.3488
          WTBLAB     0.6839
          PLSFAAB    2.4585
          PLFSAB     1.3831
          PLFSBB     1.5233
          PLFIAB     1.5688
          PLFIBB     1.5567
      / ;

Table VCMTRX(FORM,FORMb) Variance-Covariance Matrix
```

	PLMBAA	WTFLAA	WTFLBA	WTBPRAA
PLMBAA	0.1151680245	0.0067340366	0.0086850529	0.0063291237
WTFLAA	0.0067340366	0.0043997275	0.0036906089	0.0006878950
WTFLBA	0.0086850529	0.0036906089	0.0051726471	0.0002952841
WTBPRAA	0.0063291237	0.0006878950	0.0002952841	0.0012088794
WTBPCAA	0.0105834485	0.0008364081	-.0005889956	0.0034449746
WTHGBB	0.0078047416	0.0015188453	0.0005572721	0.0013226257
WTBLAB	-.0033908835	0.0009720110	0.0008306352	-.0021257665
PLSFAAB	0.1384984144	0.0063375414	0.0174181648	0.0062740209
PLFSAB	0.0252687036	0.0027703809	0.0037432356	-.0003259205
PLFSBB	0.0225519196	0.0059410895	0.0040985844	0.0034277357
PLFIAB	0.0560131211	0.0062602620	0.0055072108	0.0055718656
PLFIBB	0.0415135577	0.0047396376	0.0025845672	0.0062874535

+	WTBPCAA	WTHGBB	WTBLAB	PLSFAAB
PLMBAA	0.0105834485	0.0078047416	-.0033908835	0.1384984144
WTFLAA	0.0008364081	0.0015188453	0.0009720110	0.0063375414
WTFLBA	-.0005889956	0.0005572721	0.0008306352	0.0174181648
WTBPRAA	0.0034449746	0.0013226257	-.0021257665	0.0062740209
WTBPCAA	0.0151608112	0.0018314665	-.0072496319	0.0113986867
WTHGBB	0.0018314665	0.0033529451	-.0003378560	-.0013552383
WTBLAB	-.0072496319	-.0003378560	0.0136313883	-.0157633655
PLSFAAB	0.0113986867	-.0013552383	-.0157633655	0.2569323205
PLFSAB	0.0059378655	-.0076450876	0.0038723884	0.0628268564
PLFSBB	0.0187731388	-.0026796720	-.0039533360	0.0467572207
PLFIAB	0.0159184277	0.0042043389	-.0089156544	0.0700357991
PLFIBB	0.0234376091	0.0026808441	-.0123579495	0.0527180718

```
+             PLFSAB          PLFSBB          PLFIAB          PLFIBB

PLMBAA     0.0252687036    0.0225519196    0.0560131211    0.0415135577
WTFLAA     0.0027703809    0.0059410895    0.0062602620    0.0047396376
WTFLBA     0.0037432356    0.0040985844    0.0055072108    0.0025845672
WTBPRAA    -.0003259205    0.0034277357    0.0055718656    0.0062874535
WTBPCAA    0.0059378655    0.0187731388    0.0159184277    0.0234376091
WTHGBB     -.0076450876    -.0026796720    0.0042043389    0.0026808441
WTBLAB     0.0038723884    -.0039533360    -.0089156544    -.0123579495
PLSFAAB    0.0628268564    0.0467572207    0.0700357991    0.0527180718
PLFSAB     0.0680418821    0.0518405872    0.0190453404    0.0255901158
PLFSBB     0.0518405872    0.0656825267    0.0308781435    0.0434472778
PLFIAB     0.0190453404    0.0308781435    0.0462438498    0.0459547204
PLFIBB     0.0255901158    0.0434472778    0.0459547204    0.0561151005
;

Positive Variables

     FRAC(FORM)  Fraction of Product Form in Portfolio
     P_VAR       Portfolio Variance
     RISK        Portfolio Risk
     P_BETA      Portfolio Beta   ;

Equations

        E22       Constraint that fractions sum to one
        E23       Calculation of portfolio variance
        E24       Calculation of risk
        E25       Calculation of beta of portfolio
        E26       Risk Constraint;

     E22..      SUM(FORM, FRAC(FORM)) =E= 1.0 ;

     E23..      SUM((FORM,FORMb),FRAC(FORM)
                    *VCMTRX(FORM,FORMb)*FRAC(FORMb)) =E= P_VAR ;

     E24..      SQRT(P_VAR) =E= RISK ;

     E25..      P_BETA =E= SUM(FORM,FRAC(FORM)*BETA(FORM)) ;

     E26..      RISK =E= TARGET("T_RISK");

*********** PRODUCT FORM RECOVERY AND ECONOMIC SECTION

Parameter P(FORM)  market price by product form

/  PLMBAA     0.43
   WTFLAA     0.95
   WTFLBA     0.74
  WTBPRAA     1.05
  WTBPCAA     1.10
   WTHGBB     0.40
   WTBLAB     0.80
  PLSFAAB     1.10
   PLFSAB     0.95
   PLFSBB     1.00
   PLFIAB     0.95
   PLFIBB     1.00    /;

Table  VC(FORM,M)  variable costs of production of product forms (per lb.)
              APR     MAY     JUN     JLY     AUG     SEP     OCT
   PLMBAA  0.3130  0.3080  0.3032  0.2987  0.2987  0.2987  0.2987
   WTFLAA  0.8207  0.8098  0.7998  0.7906  0.7906  0.7906  0.7906
   WTFLBA  0.7235  0.7180  0.7130  0.7082  0.7082  0.7082  0.7082
  WTBPRAA  0.9418  0.9351  0.9291  0.9235  0.9235  0.9235  0.9235
  WTBPCAA  0.9718  0.9651  0.9591  0.9535  0.9535  0.9535  0.9535
   WTHGBB  0.2591  0.2563  0.2536  0.2536  0.2536  0.2536  0.2536
   WTBLAB  0.6157  0.6048  0.5948  0.5856  0.5856  0.5856  0.5856
  PLSFAAB  0.7110  0.7003  0.6902  0.6807  0.6807  0.6807  0.6807
   PLFSAB  0.8207  0.8098  0.7998  0.7906  0.7906  0.7906  0.7906
   PLFSBB  0.8207  0.8098  0.7998  0.7906  0.7906  0.7906  0.7906
   PLFIAB  0.6707  0.6598  0.6498  0.6406  0.6406  0.6406  0.6406
   PLFIBB  0.6707  0.6598  0.6498  0.6406  0.6406  0.6406  0.6406
       ;
```

```
Table PRR(FORM,M)   Product Recovery Rates by Month
              APR     MAY     JUN     JLY     AUG     SEP     OCT
   PLMBAA   0.3100  0.3200  0.3300  0.3400  0.3400  0.3400  0.3400
   WTFLAA   0.2100  0.2200  0.2300  0.2400  0.2400  0.2400  0.2400
   WTFLBA   0.3000  0.3100  0.3200  0.3300  0.3300  0.3300  0.3300
  WTBPRAA   0.3443  0.3607  0.3771  0.3934  0.3934  0.3934  0.3934
  WTBPCAA   0.3443  0.3607  0.3771  0.3934  0.3934  0.3934  0.3934
   WTHGBB   0.5100  0.5250  0.5400  0.5400  0.5400  0.5400  0.5400
   WTBLAB   0.2100  0.2200  0.2300  0.2400  0.2400  0.2400  0.2400
  PLSFAAB   0.1510  0.1560  0.1610  0.1660  0.1660  0.1660  0.1660
   PLFSAB   0.2100  0.2200  0.2300  0.2400  0.2400  0.2400  0.2400
   PLFSBB   0.2100  0.2200  0.2300  0.2400  0.2400  0.2400  0.2400
   PLFIAB   0.2100  0.2200  0.2300  0.2400  0.2400  0.2400  0.2400
   PLFIBB   0.2100  0.2200  0.2300  0.2400  0.2400  0.2400  0.2400
       ;

Scalar  FC  Fixed  Costs (mil. dollars)   /   15.000  /;

Positive Variables
    US_RW_FORM(Y,M,FORM)   raw weight (thous mt)
    US_FW_FORM(Y,M,FORM)   finished weight (thous mt)
    US_Y_PROD(Y,FORM)      finished weight (thous mt)
    T_PROD(Y)              total finished weight (thous mt)
    US_REV_F(Y,FORM)       us revenue (mil. $)
    US_REV_Y(FORM)         us revenue discounted (mil. $);

Variable
    US_NPV                 us npv (mil. $);

Equations
    E30(Y,M)            distribution of usable weight to product forms
    E31(Y,M,FORM)       monthly product form finished weight
    E32(Y)              calc of total production
    E33(Y,FORM)         calc of yearly production by form
    E34(Y,FORM)         product form portfolio distribution
    E35(Y,FORM)         calc of us revenue by form
    E36(FORM)           calc of discounted us revenue by form
    E37                 calc of us revenue;

E30(Y,M)$(HAR(M))..    C_MT(Y,M,"ON")$(HAR(M))  =E=
                       SUM(FORM,US_RW_FORM(Y,M,FORM))$(HAR(M));

E31(Y,M,FORM)$(HAR(M))..  US_FW_FORM(Y,M,FORM)$(HAR(M))  =E=
                      US_RW_FORM(Y,M,FORM)$(HAR(M))*PRR(FORM,M);

E32(Y)..      T_PROD(Y)=E= SUM((M,FORM),US_FW_FORM(Y,M,FORM)$(HAR(M)));

E33(Y,FORM)..  US_Y_PROD(Y,FORM)=E=SUM(M,US_FW_FORM(Y,M,FORM)$(HAR(M)));

E34(Y,FORM)..  US_Y_PROD(Y,FORM)  =E= FRAC(FORM)  * T_PROD(Y);

E35(Y,FORM)..  US_REV_F(Y,FORM)=E=SUM(M,US_FW_FORM(Y,M,FORM)$(HAR(M))
                     *2.2046*(P(FORM)-VC(FORM,M)));

E36(FORM)..  US_REV_Y(FORM)=E=SUM(Y,US_REV_F(Y,FORM)*((1/1.05)**ORD(Y)));

E37..            US_NPV =E= SUM(FORM,US_REV_Y(FORM))-FC;

C_MT.UP(Y,M,"ON")  = 30;
C_MT.UP(Y,"APR","ON")  = 15;

         C_MT.FX(Y,M,S)$(ORD(M)  LT  4  OR  ORD(M)  GT  10)=0;
US_RW_FORM.FX(Y,M,FORM)$(ORD(M)  LT  4  OR  ORD(M)  GT  10)=0;
US_FW_FORM.FX(Y,M,FORM)$(ORD(M)  LT  4  OR  ORD(M)  GT  10)=0;

ASC.FX("ON")=0.5;

**********************  SOLVE AND DISPLAY
Model wt_portl /All/ ;

   Option SOLPRINT=ON, LIMROW=0, LIMCOL=0, ITERLIM=3000, RESLIM=4000;

Solve wt_portl Using NLP Maximizing US_NPV;
```

```
Scalar  COUNT  / 0 /;

Set PORTFOLIO  /11*57 /;

Parameter  SEQ(PORTFOLIO)  / 11  0.5 /;

Model wt_port2 / ALL /;

   Loop(PORTFOLIO, TARGET("T_RISK") = SEQ(PORTFOLIO) ;
        SEQ(PORTFOLIO+1) = SEQ(PORTFOLIO)-0.01 ;

   COUNT=COUNT+1;

   Option   SOLPRINT=OFF, LIMROW=0, LIMCOL=0, RESLIM=3000;

Solve wt_port2 Using DNLP Maximizing US_NPV;
```