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TESTING FOR STRUCTURE AND MEASURING SCALE EFFECTS IN THE NORWEGIAN COD FISHERY: A PANEL DATA APPROACH

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Abstract

This study combines panel data set approaches with dual cost function methodology to model and test for structure of production in the Norwegian Cod fishery. In this study, we describe the theorems and applications of duality theory and dual cost function in the fishery. Some econometric procedures such as random effects and fixed effects estimation techniques are employed to solve the unobserved heterogeneity in the data set. Utilizing the Seemingly Unrelated Regression (SUR) procedure with the fixed effects approaches, the technical changes and scale effects of the Norwegian fishery are detected.

In this study, after a series of econometric estimation procedures, we compare results of random effect vs. fixed effects estimation technique; long-run vs. short-run equilibrium model; own-price elasticities, elasticities of substitution and scale effects. Finally, we compare the "ideal" results with the results reported in Asche, Bjørndal and Gordon (2003) that use cross-section data for the Norwegian Cod fishery.

The empirical results validate that the panel data sets are more useful in estimating both the technical changes and scale effects in the fishery than either time series or cross-section data sets. Moreover, the results confirm that the fishermen perform under the IVQs and TAC management regulations without race to fish in the Norwegian Cod fishery.

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I: Introduction

Based on either time series or cross-section data sets, a number of studies have measured for the structure of production in the fisheries. Aggregate time series data sets representing revenue and cost information for a fishery overtime have proven useful in measuring own-price elasticities and elasticities of substitution. In a study of the Canadian pacific salmon fishery, Dupont (1990) applies a profit function approach to estimate elasticities of substitution for all input pairs used in production by using time series data. However, economies of scale measures are biased because time series data do not allow identification of changes in technology that shift the average cost curve and scale effects that are measured as a movement along an average cost curve. Cross-section data sets are also common in the fishery and represent revenue and cost information at the vessel level for a particular production period. Bjørndal and Gordon (1993) employ a translog profit function to analyze a fleet's long-run and short-run profit; they consider annual cross-section data for individual vessels revenue and cost characteristics from 1969 to 1973. Such data sets allow for measures of scale effects but lacking the time dimension, measures of technical change[1] are not available. Recently, panel data have the advantage that both scale and technical change parameters are identifiable and measurable. The purpose of this research is to combine a panel data set available for the Norwegian cod fishery with the dual cost function methodology to model and test for structure in this fishery.

There are numerous studies in the fisheries economics literature that employ duality theory, either profit or cost functions, in modelling the structure of production. Jensen (2002) surveys empirical studies that utilize the theory of the firm and dual theory to reveal economic and technological conditions of fish harvesting firms. Campbell (1991), and Robinson and Pascoe (1996) employ this approach to analyze the technological properties in the fishery. A dual profit function is appropriate for modelling a fishery where both harvest level and input factors are choice variables for the fishing firm. This approach is premised on the maintained assumption that fishing behaviour is based on

[1] Technical change represents a shift in the production function over time. The rate of technical change can be define as: $T(x,t) = \partial \ln f(x,t) / \partial t$ .in the dual cost function, applying the envelope theorem, we find that the marginal cost is : $\frac{\partial c(w,y,t)}{\partial t} = -\frac{\partial c}{\partial y}\frac{\partial f(x,t)}{\partial t}$. Then, we can derive that: $T(x(w,y,t),t) = -\varepsilon^*(w,y,t)\theta(w,y,t)$. In general, technical progress raises the output obtainable for a given input bundle. Alternatively, it lower the cost of obtain in a given output. Therefore, if there exist size economies, expanding output decreases unit costs. Then the average cost will shift down. Chambers (1988) describes the Cost-neutral technical change, Cost minimization and input-augmenting technical change and profit-neutral and cost-neutral technical change individually.

profit maximization. Many fisheries, however, are regulated by total allowable catch quotas (TAC) often combined with individual vessel quotas (IVQ). Under such regulations harvest level is no longer a choice variable to the fishing firm but rather a binding constraint (i.e., a fixed factor) that fishing vessels must maintain. Under such restrictions a dual cost function can be used to model the production structure under the assumption that the fishing firms minimize the cost of harvesting the given IVQ. The Norwegian cod fishery is regulated by both a TAC and IVQs and, consequently, a dual cost function methodology will be used in modelling.

The panel data set available for estimation was provided by the Norwegian Fisheries Directorate and represents vessel level data on harvest level, expenditures for factor inputs and the physical characteristics of the vessel and engine. The data set represents a total of 55 observations, 11 firms over a five year period. The benefits of panel data stem from the modelling ability to control for both cross section and time series effects. Since panel data relate to cross-sectional units over time, heterogeneity problems across these units is an integral part. Panel data can be used to control these unit- and time-invariant variables, whereas a time series study or a cross-section study cannot. With panel data, we are able to identify and measure elasticities of substitution and own-price elasticities, and economies of scale that are simply not detectable in pure cross-section or time series data approaches individually. Finally, panel data models enable us to study more complicated behavioural models. For example, technical efficiency is better studied and modeled with panels (Baltigi and Griffin (1998b)).

In this research, we are interested in studying a number of problems. First, what are the benefits of using the duality theory and cost function estimation to model the structure of production? Second, what procedures are available to convert for the unobserved heterogeneity in panel data? A seemingly unrelated regression (SUR) procedure is used in estimation. We are interested in comparing short-run vs. long-run model and fixed effects vs. random effects estimation techniques; results of own-price elasticities, results of Allen elasticities of substitution and scale effects under a number of restrictions. Finally, we compare our "best" results with those reported in a recent article by Asche, Bjørndal and Gordon (2003) that use a cross section data set for the Norwegian Cod fishery.

Under TAC and IVQs fishery regulations, the harvest level of is the fixed factor. Hence, cost minimization function is equal to the profit maximization because fishermen only can vary their input compositions under fixed output level. Hence, obtaining the minimization cost implicates the maximization profit will happen simultaneously (see Jensen (2002)). The dual cost function approach is employed to model the production structure. Within the dual cost function approach, this thesis uses a panel data set combined with either a fixed effects or the random effects estimation procedure to overcome the omitted variables problems existing in the either cross-section or time series data approaches (see Lindquist (1998)). With the fixed effects estimation approach, using both of time series and cross-section dummy variables, these heterogeneity problems caused by time- or unit-invariant variables are solved. Using a Hausman specification test, the fixed effects approach with both the time series and cross-section binary variables is appropriate. Under both the long-run and short-run equilibrium models, the estimation parameters of the Allen elasticities of substitution, own-price elasticities are obtained by using the iterative Seemingly Unrelated Regression procedure combined with the fixed effects approach. After this estimation step, this study makes the null hypothesis that the capital is a variable input in the cost function. At the same time, the alternative hypothesis is defined that the capital variable is a quasi-fixed variable. Applying a Kulatilaka (1984) test, the estimate confirms the long-run cost function in this study.

In this study, the empirical results show that input factors of labour and capital, labour and fuel, capital and miscellaneous, miscellaneous and fuel are Allen substitutes. However, input factors of labour and miscellaneous, capital and fuel are Allen complements. The own-price elasticities are all negative and rather inelastic. Moreover, the thesis investigates that both the time series and the cross-section dummy variables have noticeable effects on the total costs. Comparing with the estimation parameters in

Asche, Bjørndal and Gordon (2003), the absolute values of own-price elasticities and Allen elasticities of substitution are greater in this study. Finally, the positive value of economies of scale in this thesis validates that the Norwegian fishery has not race to fish, which result is derived from Asche, Bjørndal and Gordon (2003). According to these results of economies of scale, own-price elasticities and elasticities of substitution in the long-run model, we affirm that the panel data approach is suitable for measuring the techniques changes and scale effects in the fishery.

The rest of this thesis is outlined as follows. In Chapter II, the relevant literature review of duality theory and the dual cost and profit function in modelling are presented. A number of reference issues of duality theory with cost function or profit function in the fishery are presented in this chapter. In chapter III, this study discusses the modelling issues of the dual cost function. The second section of Chapter III explains long-run and short-run cost functions A Kulatilaka (1985) test is also described. In the following part, the translog cost function form is described and the Allen elasticities of substitution, cost shares and economies of scale are derived. Following the discussions of those approaches, In Chapter III, this thesis presents the background and the advantages of panel data sets. In the following part, Chapter III describes econometric issues of the fixed effects and the random effects assumptions. Afterwards, Hausman specification procedures used to select the fixed effects model and random effects model are presented in this chapter. Chapter

III also provides the literature review of the Seemingly Unrelated Regression procedure. In the chapter IV, this study briefly provides a description of the basic statistic and characters of the fishery data. Chapter V presents the estimated results. Chapter VI uses these estimation parameters derived from the long-run equilibrium model to compare with those results reported in Asche, Bjørndal and Gordon (2003). Concluding remarks are drawn in Chapter VI.

II. The Literature Review of Duality between Cost and Profit Functions.

In neoclassical economics, two approaches have been used to model the technological structure of production. The traditional or primal procedure directly estimates the production function and obtains the technological parameters. Hannesson (1983), Campbell (1991), and Robinson and Pascoe (1996) describe this approach to analyze the technical properties in the fishery. The primal procedure first assumes that the parameters of production are estimated directly based only on the technical parameters without requiring behavioural assumptions. This procedure only employs the physical characters of inputs and outputs, while the procedure does not employ the economic behaviours of profit maximization or cost minimization. All input variables are assumed as exogenous in this approach.

However, there are two significant disadvantages. First, simultaneity bias will be a problem when the input variables are correlated with the disturbance terms in the production function. In this case, where inputs are endogenous, direct estimates of production function are inconsistent (Mundlak 1996). Second, Input variables are often highly collinear, and this will cause multicollinearity problems[2] in the estimation.

The problems with direct estimation coupled with the derivation and application of duality theory in economics serve to facilitate the indirect estimation of the profit function approach. The dual approach is suitable for dealing with the problems of the input quantities in fisheries. This indirect approach utilizes the duality between costs, prices and quantities. Economic behaviours such as profit maximization or cost minimization can be estimated by using this procedure. Indirect estimation applies the duality theory. It analyzes optimization problems in which technological properties are derived by employing the envelope theorem, and are based on the profit or cost function[3]. Gorman (1976) provide the most succinct definition of dual theory. He states "[D]uality

[2] If a model has several variables, it is likely that some of the explanatory variables will be approximately linearly related. This property, known as multicollinearity, can drastically alter the results from one model to another, thus making it more difficult to interpret results. If some explanatory variables are nearly linearly related, the OLS estimators are still BLUE and MLE and hence are unbiased, efficient and consistent. The covariance between the regression coefficients of a pair of highly correlated variables will be very high, in absolute value, thus making it difficult to interpret individual coefficient. (see Gujarati (2003))

[3] McFadden (1978) generalized Shephard's duality concepts to include both revenue and profit functions. Normally, the revenue approach is rarely employed, in large part due to the fact that layering in the additional assumption of cost minimization results in simultaneity problems. The profit function approach, in contrast to the cost and revenue function techniques, is not burdened with simultaneity problems in the explanatory variables provided that the firm is a price taker in the marketplace for inputs and outputs. However, separating input substitution from scale effects under the profit function methodology remains problematic, and obtaining information with respect to whether or not the inputs is normal, superior or inferior is fraught with difficulties (Woodland 1997,Binswanger and Evenson, 1980) (see Chambers (1988))

is about the choice of the independent variables in terms of which one defines a theory." That is, the essence of the dual approach is that technology restricts optimizing behaviours of firms. Diewert (1974) and McFadden (1978) investigate the dual relationship between profit and production functions, by employing prices as regressors; the dual approach is a complementary one, suitable for dealing with input problems.

The dual approach has the advantage of modelling multiproduct technology properties. No first-order conditions require to be solved when applying the dual approach. This means that a wide range of functional forms can be utilized by the dual approach. Moreover, the dual approach is based on price data, which are often more readily available and accurate than quantity data. Applications of the dual approach in the firm utilize three different sets of behavioural hypotheses and accompanying objective functions to describe firm behaviour. There are: profit maximization, input constrained revenue maximization, and output constrained cost minimization. (Jensen (2002))

Salvanes and Squires (1995) employ the multiproduct profit function, $\pi(p,w)$ to describe the profit-maximizing firm presented by:

$$\pi(p,w) = Max\{py - wx\}$$

$$\text{s.t } f(y,x) = 0$$

where p is price of output, y is the output, and w is the price of input factor x. It is assumed that the firm is a price-taker in the input and output markets. The properties imply that $\pi(p,w)$ is nonnegative, nondecreasing in p, decreasing in w, positively and linearly homogeneous, convex, and continuous (p,w).

Kirkley and Strand (1998), Squires and Kirkley (1991) employ revenue maximizing behaviour to describe the short-run multiproduct supply structure at given levels of inputs. In the short run, inputs are fixed and the firm maximizes the revenue function:

$$R(p,x) = \max\{py;x\}$$

The firm is a price-taker in the output markets, and the inputs are fixed at their short-run levels. The output supply is conditioned on perceived output prices, p. The $R(p,x)$ is nondecreasing in p, convex and continuous in p, nondecreasing and nonnegative in x.

Bjørndal and Gordon (2000), Weninger (1998) employ the behavioural hypothesis of cost minimization to present firms operating under output regulation. The output-constrained firm minimizes the cost function:

$$C(w,y) = Min\{wx;y\}$$

s.t $y = f(x)$

Such firms are assumed to base their input demand on the input prices for given output levels. The properties imply that $c(w,y)$ is positive for $y > 0$, nondecreasing in w, concave and continuous in w, positively and linearly homogeneous in w, nondecreasing in y , and since the profit is always nonnegative, then

$$c(w,0)=\max_{p>0}\{p.0-\Pi(p,w)\}=\min_{p}\Pi(p,w)=0$$

Therefore, cost minimization is a relevant option for describing firms that vary their input compositions, while output supply functions are restricted and vertical due to output regulation or biological constraints.

In a study of the Canadian pacific salmon fishery, Dupont (1990) applies a dual profit function approach to estimate elasticities of substitution for all input pairs of production by using the pure time series data set. Thunberg, Bresnyan, Adams (1995) reveal cross-price elasticities for gill net technology. Guttormsen (2002) employs the dual cost function approach to model the technical structure of the Norwegian farmed salmon. He examines the change in technology by testing whether several input factors are substitutes in the production process. Tvetrås (2002) combine dual production function approach with the time series data to model and analyze the relationship between environmental quality and industry growth the structure of the Norwegian salmon aquaculture. Weninger (1998) use the dual cost function to model and estimate the economies of scope in the mid-Atlantic surf clam and ocean quahog fishery, where fishermen are restricted by output regulation. Bjørndal and Gordon (1993) employ dual profit function with annual cross-section data approach to analyze a fleet's long-run and short-run profit; Asche, Bjørndal and Gordon (2003) use long-run cost function to model the production technology for a fishery regulated with Individual Vessel Quotas. To evaluate overcapacity in a fishery managed with individual vessel quotas, they measure rents generated and potential rents and use annual cross-section data to estimate the economies of scale, own-price elasticities and Allen elasticities of substitution.

The dual approach reveals that various aspects of fish harvesting such as the firm's supply and transformation between outputs, input demand and substitution between inputs, long-run investment intentions, and the estimation of scale changes by introducing IVQ management[4] in the fishery. In those studies, dual applications show that significant efficiency gains can be obtained by a transition form unregulated or limited-access fishery to IVQ-managed fishery. Grafton, Squires and Fox (2000) confirm the rents are generated in the Canadian pacific halibut fishery when the fisheries choose IVQ schemes.

III. Model Specification and Discussion

3.1 Application of Dual Cost Function

Modelling the fish harvesting process, we assume that obtaining maximum profit is

[4] During 1990s, the individual vessel quota (IVQ) regulations have become an important management tool. Under these regulations, the quota may or may not be transferable. These regulations eliminate the race to fish as fishermen are ensured their quota share and can generate rent.

the desired outcome. Using the profit function to estimate production parameters, input variables used in the fishing industry are all choice variables.

Total profits can be written as:

$$\max_{Y,q} \Pi(p,w) = Yp - \sum_i q_i w_i \qquad (1)$$

s.t $f(Y,q) = 0$

where p is the price of fish, Y is the harvest output, and w_i is the price of i^{th} input factor q_i. The profit is the difference between revenue and cost of production.

Dupont (1990) considers that observed profits are estimated as the resource rent. In an open access fishery or in a regulated open access fishery (Total Catch Quota-TAC), the common property nature of the fishery will deplete resource rents, resulting in zero profits. During the 1990s, the individual vessel quotas (IVQ) system was introduced, and IVQ transferability was an issue. A well-designed individual transferable quota system allows all resource rent to be captured; therefore, profits or resource rents will become positive.

The profit function, dependent on equation (1), can be restricted to account for fixed input in the fishing industry. Generally, capital (the fishing vessel) should be treated as exogenous and fixed factor in harvesting. The restricted profit function is specified, where the fishing vessel is assumed to obtain maximize profits. Choosing inputs and harvest levels corresponding to the size of the vessel used in harvesting, the restricted profit function can be defined as:

$$\pi = \pi^R(p, w, k)$$

Also, the total profit can be defined as:

$$\pi = \pi^q - qk\,.$$

This thesis considers that a Total Catch Quota (TAC) controls the total harvest. The output Y is a fixed factor; maximum profits for a given catch quota are obtained when the cost of harvesting the given quota is minimized. If one employs prices as regressors, the dual approach offers a complementary cost approach that is highly suitable for dealing with the problems of input quantities.

The cost function contains all the choice variables for the fishery industry under an IVQ scheme. Lau (1976) employs the same theory to point out that a cost function is a special form of a restricted profit function, when the harvest level is treated as a fixed factor[5].

The cost minimization function can be defined as:

$$\min C = \sum_{i=1}^{n} X_i W_i \qquad (i = 1, 2 \ldots, n) \qquad (2)$$

[5] In general, direct estimation of the production function is preferred where the level of output is endogenous. However, estimation of the cost function is more appropriate where the level of output is exogenous. (Christensen and Greene 1976).

subject to

$$Y = f(X_1, X_2, ...X_k) \quad (3)$$

Where X_i= inputs levels, W_i=factor prices, Y=output.

There exists a dual minimum cost function.

$$C^* = (Y, W_1, ...W_{k-1}, W_k) \quad (4)$$

The cost function assigns to every combination of input prices the minimum cost corresponding to the cost minimizing input levels X_i^*. C^* is homogeneous of degree one in prices. According to Diewert (1971), the Shephard's Lemma[6] can be dealt with by the cost function:

$$\frac{\partial C^*(Y, W_1, ...W_k)}{\partial P_i} = X_i^* \quad (5)$$

Let f be the bordered Hessian matrix of function (2) and $f_i = \partial Y / \partial X_i \quad f_{ij} = \partial^2 Y / \partial X_i \partial X_j$.

So Allen partial elasticities can be defined as:

$$\sigma_{kr} = \sum_{i=1}^{n} X_i f_i (f^{-1})_{rk} / X_k X_r \quad (6)$$

Where $(f^{-1})_{rk}$ is the rk^{th} element of f^{-1}. From function (6), it is apparent that

$$\sigma_{kr} = \sigma_{rk} \quad (7)$$

In the case of the cost function, estimates of σ_{kr} can be obtained directly from the parameters of the function (Uzawa 1962).

[6] See Appendix A

$$\sigma_{kr} = \frac{\sum_{i=1}^{n} W_i X_i}{X_k X_r} \frac{\partial^2 C^*}{\partial W_r \partial W_k} \qquad (8)$$

If $\sigma_{kr} > 0$, input k and r are Allen substitutes. Otherwise they are Allen complements if the inequality is reversed. That is, two inputs are Allen substitutes if an increase in the price of one leads to an increase in the utilization of the other. If the inputs are Allen substitutes, an increase in W_j will increase the ratio $x_i(W,Y)/x_j(W,Y)$. On the other hand, two inputs are Allen complements if an increase in the price of one leads to decreased utilization of the other.

3.2 Short-run and Long-run Equilibrium Models and the Kulatilaka Test

This thesis assumes a twice differentiable aggregate cost function in the Norwegian Cod fishery, which relates the flow of gross fish output (Y) and four inputs: capital (K), labour (L), miscellaneous costs (M), and fuel cost (F). According to Kulatilaka (1985), a short-run equilibrium is the equilibrium where some factors can adjust to their long-run levels within a single period, while others (the quasi-fixed ones) will be adjusted only partially. If the observed technology is in fact in a long-run equilibrium, then these "optimal" long-run levels of the quasi-fixed factors should equal the observed short-run levels. Kulatilaka (1985) suggests to start with testing a full static equilibrium model against a short-run equilibrium model (with one quasi-fixed factor). If the result is significantly different from zero, the long-run equilibrium model should be rejected.

Normally, the long-run cost function is defined as:

$$C = C(P;Y) \qquad (9)$$

where P= (p_1, p_2,……p_n) is the vector of input factor and C is the minimum value of the total input costs to produce the output level Y. According to Shephard's Lemma, the expenditure share is defined as:

$$S_i = \partial \ln C / \partial \ln p_i \qquad i \in (1,2,.....n) \qquad (10)$$

where S_i is the expenditure share for factor i, and $\sum S_i = 1$

In contrast to the long-run model, the short-run equilibrium model depicts a situation where observations are made when some input variables are fully adjusted to the variable cost-minimizing levels and others are only partially adjusted to the cost-minimizing levels. The former factors are called variable factors (indexed by 1,……m) and the latter factors are defined as quasi-fixed factors (indexed by m+1,……n). The short-run equilibrium will be equal to the long-run equilibrium if the quasi-fixed factors can adjust to the full-cost minimizing levels.

Kulatilaka (1985) uses the restricted cost equation $CR = CR(P';Z,Y)$ to provide a functional characterization of a technology that reaches a short-run equilibrium. The vector $P'(p_1, p_2,..., p_n)$ denotes the variable input prices; CR is the variable cost of producing an output level Y under the prices P and the quasi-fixed levels Z. Applying the envelope theory[7], the shares of variable cost can be defined as:

$$S_i' = \partial \ln(CR)/\partial \ln(p_i) \qquad i \in (1,.....m) \tag{11}$$

where $\sum S_i' = 1$

the total cost function is written as:

$$CT(P,K,Y) = CR(P',K,Y) + P''K \tag{12}$$

where $P'' = (p_{m+1},.....p_n)$ is the price vector of the quasi-fixed factors.

With respect to the (n-m) quasi-fixed inputs, the long-run cost function $\hat{C}$ is obtained by minimizing CT while holding the first m inputs and the level of output at the observed variable cost-minimizing levels.

$$\hat{C} = \min_k CT \tag{13}$$

$$\partial CT/\partial K = (\partial CR/\partial K) + P'' = 0 \tag{14}$$

where we find:

$$\partial CT/\partial K = (\partial CT/\partial K_{m+1},......,\partial CT/\partial K_n) \tag{15}$$

Suppose $\hat{K}$ equals to K, and $\hat{K}$ is defined as the "desired" long-run levels.

The cost function is written as:

$$\hat{C}(p,Y) = CR(p',\hat{K}(p,Y),Y) + p''(p,Y) \tag{16}$$

[7] See appendix B

The term $\partial CR / \partial K$ is the reduction in variable costs for a unit increase in the level of the quasi-fixed input variables. Therefore, $-\partial CR / \partial K$ is the shadow value of the quasi-fixed input i. If the cost can meet the long-run minimizing level, the shadow price equals to the market price and $-\partial CR / \partial K$ should equal the observed prices p'' at that moment.

As we have seen the long-run model can be thought of as a special case of the short-run equilibrium model. However, it can be derived from the short-run model by imposing restrictions on the parameters. In fact, the short-run and long-run models are estimated on different data: first, the long-run model on total costs and input costs as shares of total cost. Second, the short-run model the restricted cost function on variable costs and input costs as shares of variable costs, while conditioning on the quasi-fixed inputs. The null hypothesis can be stated that observed quasi-fixed factors are at their long-run desired levels, since the validity of the long-run model requires the null to be true; a rejection of the null will invalidate a long-run model specification.

The null hypothesis in quantity space requires that the observed levels of quasi-fixed factors, K, equal their long-run desired levels, $\hat{K}_t$.

Null hypothesis: $K_{it} = \hat{K}_{it}(\beta, \varepsilon, p_t, Y_t)$, $i \in (m+1......,n)$. $t \in (1......n)$. (17)

where β is the vector of estimated parameters and ε is the additive error term introduced in estimating the restricted cost function. This test is to form confidence intervals around $\hat{K}_{it}$ to test if K_{it} falls within these intervals. The $\hat{K}_{it}$ values can be obtained by solving the first-order condition of the long-run cost minimization problem since $\hat{K} = \hat{K}(P, Y, \beta, \varepsilon)$. When the distributions of β and ε and the function $\hat{K}(.)$ are known, I compute the distribution of $\hat{K}_{it}$. The variance of $\hat{K}$ is computed as follows:

$$V(\hat{K}_i) = (\partial \hat{K}_i / \partial \beta) V(\beta) (\partial \hat{K}_i / \partial \beta)' + (\partial \hat{K}_i / \partial \varepsilon) V(\varepsilon) (\partial \hat{K}_i / \partial \varepsilon)' \qquad (18)$$

Where $V(\beta)$ and $V(\varepsilon)$ are the covariance matrices of β and ε. $V(\varepsilon)$ is estimated as the sum of squared residuals divided by the degrees of freedom.

$$\left[\partial \hat{K}_i / \partial \beta\right] = -CR_{K_t \beta} / CR_{K_t K_t} \qquad (19)$$

And

$$\left[\partial \hat{K}_i / \partial \varepsilon\right] = -CR_{K_t} / CR_{K_t K_t} \qquad (20)$$

Where the subscripts on CR denote partial derivatives.

Since this study uses a linear approximation under the assumption of normally distributed ε and β, the distribution of $\hat{K}_{it}$ will also be normal. A consistent and efficient estimate of the variance of ε, $V(\varepsilon)$, is estimated as the sum of squared residuals divided by the degrees of freedom.

Since a linear approximation under the assumption of normally distributed ε and β is employed, the distribution of K_{it}^* is normal. Alternatively, the test statistic,

$$t_0 = (\hat{K}_{it} - K_{it}) / \left[V(\hat{K}_i) \right]_{tt}^{1/2}$$

Will be t-distributed. Since t_0 is asymptotically standard normal, we perform a more powerful joint test by comparing the mean squared deviation between the time paths of K_i and $\hat{K}_i$.

When the joint covariance matrix, $V(\hat{K}_i)$, is known, the test statistics computed as:

$$\chi_N^2 = (\hat{K}_{it} - K_{it})' V(\hat{K}_i)^{-1} (\hat{K}_{it} - K_{it}) \tag{21}$$

Will be distributed as a chi-squared of degree N, where N is the number of observations.

Jensen (2002) handles a full static equilibrium production function and hypothesizes that capital is variable[8]. His work is quite convincing and the null hypothesis of variable capital could not be rejected. Asche, Bjørndal and Gordon (2003) apply the same estimation method used by Kulatilaka (1985)[9] to test the null hypothesis of full static equilibrium; they found that variable capital should be applied in the cost function. A repeated application of this process is used to validate the long-run equilibrium model.

$$\begin{aligned} FSE &= f(w_{labour}, w_{capital}, w_{miscellaneous}, w_{fuel}, Y) \\ SRE &= f(w_{labour}, K_{capital}, w_{miscellaneous}, w_{fuel}, Y) \end{aligned} \tag{22}$$

According to the empirical result of the Kulatilaka (1985) test, the short-term equilibrium

[8] Applications of the dual approach mainly outline the firm's short-term behaviour, treating vessel capacity as quasi-fixed. In short-term equilibrium, quasi-fixed vessel capacity can be used to represent the fixed capital factor. Therefore, all applications specify GRT (Gross Registered Tonnage) as the single quasi-fixed input. the test of the quasi-fixed input is based on the behaviour of the firm in the short-term; i.e., when vessel capacity is quasi-fixed. (Jensen (2002))

[9] Kulatilaka (1985) also proposes a test comparing the actual prices of the quasi-fixed inputs and the statistic equilibrium prices implicitly defined by equation: $P_{it}^* = \left[\partial CR / \partial K_i \right]_t$

model with capital as fixed and labour, miscellaneous, fuel as variable should be rejected in this study.

3.3 Translog Cost Function

The translog cost function is written as a logarithmic Taylor series expansion to the second term of a twice-differentiable analytic cost function around variable levels of 1. Rewrite equation (3) in natural logarithms:

$$\ln C^* = f(\ln Y, \ln W_1, \ldots \ln W_n) \tag{23}$$

The first and second order derivatives can be denoted at ln(.)=0 as follows:

$$\ln C^*\big|_0 = \alpha_0 \;\; ; \frac{\partial \ln C^*}{\partial \ln Y}\bigg|_0 = \alpha_Y \;\; ; \;\; \frac{\partial \ln C^*}{\partial \ln W_i}\bigg|_0 = \alpha_i \, ; \;\; \frac{\partial^2 \ln C^*}{\partial \ln W_i \partial \ln W_j}\bigg|_0 = \alpha_{ij}$$

$$\frac{\partial^2 \ln C^*}{\partial \ln Y \partial \ln Y}\bigg|_0 = \alpha_{YY} \, ; \;\; \frac{\partial^2 \ln C^*}{\partial \ln W_i \ln Y}\bigg|_0 = \alpha_{iy} \tag{24}$$

These functions imply the symmetry constraint:

$$\alpha_{ij} = \alpha_{ji} \tag{25}$$

Then, the Taylor series expansion is as follows:

$$\begin{aligned} \ln C = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln W_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij} \ln W_i \ln W_j + \alpha_Y \ln Y \\ + \frac{1}{2} \alpha_{YY} (\ln Y)^2 + \sum_{i=1}^{n} \alpha_{iY} \ln W_i \ln Y \end{aligned} \tag{26}$$

and the associated cost shares will be:

$$S_i = \frac{\partial \ln C(W,Y)}{\partial \ln W_i}$$
$$= \alpha_i + \sum_{i=1}^{n} \alpha_{ij} \ln W_j + \alpha_{iY} \ln Y \tag{27}$$

The following restrictions were imposed as:

Homogeneity: $\sum_{i=1}^{n} \alpha_i = 1, \sum_{i=1}^{n} \alpha_{ij} = 0, \sum_{j=1}^{n} \alpha_{ij} = 0, \sum_{i=1}^{n} \alpha_{iY} = 0$

the i^{th} cost share can be written as:

$$S_i = \frac{W_i i}{C} \tag{28}$$

According to Binswanger (1974), the α_{ij} is related to variable elasticities of substitution. The Allen elasticity of substitution can be measured from the fitted cost and share equations. Therefore, the elasticities of substitution for i, j are defined as follows:

$$\sigma_{ij} = \frac{\alpha_{ij} + S_i S_j}{S_i S_j} \quad \text{for all } i \neq j \tag{29}$$

$$\sigma_{ii} = \frac{\alpha_{ii} + S_i^2 - S_i}{S_i^2} \quad \text{for all } i \tag{30}$$

And the own-price elasticity is

$$\eta_i = \sigma_{ii} S_i \tag{31}$$

This thesis follows Christensen and Greene (1976) in calculating Economies of Scale as:

$$SE = 1 - \partial \ln C / \partial \ln Y \tag{32}$$

Where a positive value indicates economies of scale and a negative value indicates diseconomies of scale. Holding prices constant at mean level, the translog specification of economies of scale is defined as

$$SE = 1 - (\alpha_y + \alpha_{yy} Y) \tag{33}$$

Berndt and Wood (1975) employ another way to justify the Allen elasticities of substitution.

$$\alpha_{ij} = \left.\frac{\partial^2 \ln C}{\partial \ln W_i \partial \ln W_j}\right|_0$$

$$= W_j \frac{\partial}{\partial W_j}\left(\frac{\partial C}{\partial W_i}\frac{W_i}{C}\right)$$

$$= W_j\left(\frac{\partial^2 C}{\partial W_i \partial W_j}\frac{W_i}{C} - \frac{W_i}{C^2}\left(\frac{\partial C}{\partial W_i}\right)\left(\frac{\partial C}{\partial W_j}\right)\right) \tag{34}$$

and

$$X_K = \frac{\partial C}{\partial K}, X_L = \frac{\partial C}{\partial L}, X_M = \frac{\partial C}{\partial M}$$

$$\alpha_{ij} = \frac{W_i W_j}{C}\frac{\partial^2 C}{\partial W_i \partial W_j} - \frac{W_i W_j}{C^2} X_i X_j \tag{35}$$

Then one can find:

$$\frac{\partial^2 C}{\partial W_i \partial W_j} = \frac{\alpha_{ij} C}{W_i W_j} + \frac{C}{W_i W_j} S_i S_j \tag{36}$$

Substituting function (35) into equation (8):

$$\sigma_{rk} = \frac{\sum_{i=1}^{n} W_i X_i}{X_k X_r}(\alpha_{ij} + S_i S_j)$$

$$= \frac{\alpha_{ij} + S_i S_j}{S_i S_j} \tag{37}$$

Similarly, using the same method, one also shows that $\sigma_{ii} = (\frac{\alpha_{ii} + S_i + S_j}{S_i^2})$

Following the explanations of microeconomics approaches, this research presents the econometric estimation procedures. At first, this thesis introduces the background and explains the merits of utilizing panel data.

3.4 The Background of Panel Data

The panel data approach has several important advantages. First, panel data can control the individual heterogeneity problems. For example, a lot of variables of panel data change with cross-sectional units and time. At the same time, there are still many variables that may be unit-invariant or time-invariant that can influence consumption. The sole use of time-series data or cross-section data to estimate will cause biased results and serious misspecification. Panel data approaches can be used to measure successfully the fishery technique changes and scale effects of the total fish industry. Second, panel data sets will provide more information data, more variability, less collinearity among variables, more degrees of freedom and more efficiency. Employing more informative panel data set, Todani (2000) analyzes the pricing behaviour of railroads in the coal transportation market in the US, with special reference to the transportation of coal to electric utilities. Third, Ben-Porath (1970) illustrates that panel data are better able to identify and measure effects that are simply not detectable in pure cross-section or pure time-series data. Finally, the panel data model allows one to construct and test more complicated behavioural models than a pure time-series or a cross-section data set (Hsiao (1996)).

3.5 Fixed Effects and Random Effects Approaches

The econometric estimation procedures of fixed effects and random effects approaches are described in this section. Choosing an accurate panel data regression model is the starting point of estimation process. There are two important estimation techniques to analyze panel data: the fixed effects model (FEM) approach and the random effects model (REM) approach.

The fixed effects regression model has n different intercepts, one for each entity. These intercepts can be represented by a set of binary variables. These binary variables absorb the influences of all omitted variables that vary from one entity to the next but are constant over time or that change over time but are constant from one entity to the next.

The fixed effects model is given by:

$$y_{it} = \beta_0 + \beta_1 x_{2,it} + \beta_2 z_i + \beta_3 x_{3,it} + \ldots + \beta_k x_{k,it} + \varepsilon_{it} \qquad \text{i=1,2,3.....n}$$

$$t=1,2,3\ldots\ldots T \tag{38}$$

where y_{it} is the output and x_{it} the vector of inputs for the ith firm in the tth period; where Z_i is an unobserved variable that varies from one state to the next but does not change over time. Because Z_i varies from one state to the next but is constant over time, the population regression model in equation (38) can be interpreted as having n intercepts, one for each state. Specifically, let $\alpha_i = \beta_0 + \beta_2 Z_i$. Then this equation becomes:

$$Y_{it} = \beta_1 x_{1,it} + \alpha_i + \beta_3 x_{3,it} + \ldots + \beta_k x_{k,it} + \varepsilon_{it} \tag{39}$$

equation (39) is the fixed effects regression model, in which $\alpha_1,\ldots,\alpha_n$ are treated as unknown intercepts to be estimated, one for each state. The fixed effects approach takes α_i to be a group specific constant term in the regression model. We assume $\varepsilon_{it} \sim IID(0,\sigma^2)$. This model can be estimated by including N-1 intercept dummy variables

$$Y=\begin{bmatrix} y_1 \\ \cdot \\ \cdot \\ y_n \end{bmatrix}=\begin{bmatrix} i \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{bmatrix}\alpha_1^*+\begin{bmatrix} 0 \\ i \\ \cdot \\ \cdot \\ \cdot \\ 0 \end{bmatrix}\alpha_2^*+\ldots+\begin{bmatrix} 0 \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ i \end{bmatrix}\alpha_N^*+\begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_n \end{bmatrix}\beta+\begin{bmatrix} \varepsilon_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \varepsilon_n \end{bmatrix} \tag{40}$$

or $y=[d_1 \;\; d_2 \;\; d_3 \;\; \ldots d_n \;\; X]\begin{bmatrix} \alpha \\ \beta \end{bmatrix}+\varepsilon$

where d_i is a dummy variable indicating the *ith* unit. Let ε_i be associated $T\times 1$ vector of distribances. Let the $nT\times n$ matrix $D=[d_1,d_2,d_3 \ldots d_n]$. Then, the equation (39) can be presented as:

$y = D\alpha + X\beta + \varepsilon$

where $E(\varepsilon_{it} | x_i, \alpha_i) = 0,$ t=1,2,...,T.

$$E(\varepsilon_i \varepsilon_i' | x_i, \alpha_i) = \sigma_\varepsilon^2 I_T$$

I_T denotes the $T \times T$ identity matrix.

$\overline{y}_i = T^{-1} \sum_{t=1}^{T} y_{it}$, $\overline{x}_i = T^{-1} \sum_{t=1}^{T} x_{it}$ and $\overline{\varepsilon}_{it} = T^{-1} \sum_{t=1}^{T} \varepsilon_{it}$ then:

$y_{it} - \overline{y}_i = (x_{it} - \overline{x}_i)\beta + \varepsilon_{it} - \overline{\varepsilon}_i$ or $\ddot{y}_{it} = \ddot{x}_{it}\beta + \ddot{\varepsilon}_{it}$,

The fixed effects estimator can be expressed as[10]:

$$\hat{\beta}_{FE} = (\sum_{i=1}^{N} \ddot{X}_i' \ddot{X}_i)^{-1} (\sum_{i=1}^{N} \ddot{X}_i' \ddot{y}_i) = (\sum_{i=1}^{N} \sum_{t=1}^{T} \ddot{x}_{it}' \ddot{x}_{it})^{-1} (\sum_{i=1}^{N} \sum_{t=1}^{T} \ddot{x}_{it} \ddot{y}_{it})$$

This study adds n-1 time series binary variables, and t-1 cross-sectional binary variables into equation (25), and both of them into the translog cost function to absorb the influences of all omitted variables.

The translog cost function can be rewritten as follows:

$$\begin{aligned}\ln C_{m,t} &= \alpha_m + \beta_2 D1_m + \beta_3 D2_m + \ldots + \beta_n Dn_m + \phi_2 T2_t + \ldots + \phi_n Tn_t + \frac{1}{2}\sum_{i=1}^{n} \alpha_{i,t} \ln W_{m,i,t} \\ &+ \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_{i,j,t} \ln W_{m,i,t} \ln W_{m,j,t} + \alpha_{Y,t} \ln Y_{m,t} + \frac{1}{2}\alpha_{YY,m,t} (\ln Y_{m,t})^2 \\ &+ \sum_{i=1}^{n} \alpha_{i,Y,t} \ln W_{m,i,t} \ln Y_{m,t} + remainder\end{aligned} \quad (41)$$

[10] The derivations of all equations are presented in Greene (2000)

where subscripts m and t refer to fleet number and years, k is the dummy number and i, j represent to inputs. $T2_t.....Tn_t$ are time dummy variables. $D2_m.....Dn_m$ are cross-section dummy variables[11].

Beginning with the same unobserved effects model as before:

$$Y_{i,t} = \beta_0 + \alpha_i + \beta_1 X_{1,i,t} + \beta_2 X_{2,i,t} + u_{i,t} \tag{42}$$

assuming the unobserved effect, α_i, has zero mean. If the unobserved effect α_i is correlated with any explanatory variables, the fixed effects approach should be used. Equation (41) becomes a random effects model when this study assumes that the unobserved effect α_i is uncorrelated with each explanatory variable:

$$\text{cov}(x_{itj}, \alpha_i) = 0, \quad t=1,2,\ldots..T; j=1,2,\ldots,k. \tag{43}$$

If we define the composite error term as $v_{it} = \alpha_i + u_{it}$, the equation (42) can be written as:

$$y_{it} = \beta_0 + \beta_1 x_{it1} + \ldots + \beta_k x_{itk} + v_{it} \tag{44}$$

The usual assumptions of random effect model are:

$$\alpha_i \sim N(0, \sigma_\alpha^2)$$
$$u_{it} \sim N(0, \sigma_u^2)$$

$$E(\alpha_i u_{it}) = 0 \qquad E(\alpha_i \alpha_j) = 0 \qquad (i \neq j)$$

$$E(u_{it} u_{is}) = E(u_{it} u_{jt}) = E(u_{it} u_{js}) = 0 \qquad (i \neq j;\ t \neq s)$$

[11] Actually, we cannot include all n binary variables plus a common intercept, because if we do this, the regressors will be perfectly multi-collinear. Instead, we arbitrarily omit the cross-section binary variable D1 and time dummy variable T1.

Hence, we can find the result:

$\Omega \equiv E(\omega_i \omega_i^{'})$

and $E({u_{it}}^2) = 0$ all t are not equal to s

$$E(\omega_{it}^2) = E(\alpha_i^2) + 2E(\alpha_i u_{it}) + E(u_{it}^2) = \sigma_\alpha^2 + \sigma_u^2 \tag{45}$$

Therefore, Ω takes the special form:

$$\Omega = E(\omega_i \omega_i^{'}) = \begin{pmatrix} \sigma_\alpha^2 + \sigma_u^2 & \sigma_\alpha^2 & .. & .. & \sigma_\alpha^2 \\ \sigma_\alpha^2 & \sigma_\alpha^2 + \sigma_u^2 & .. & .. & . \\ . & . & .. & .. & . \\ . & . & .. & .. & . \\ \sigma_\alpha^2 & . & .. & .. & \sigma_\alpha^2 + \sigma_u^2 \end{pmatrix} \tag{46}$$

Hence, the matrix can be written as:

$$\Omega = \sigma_u^2 I_T + \sigma_\alpha^2 j_T j_T^{'} \tag{47}$$

Ω depends only on two parameters σ_α^2 and σ_u^2, The correlation between the composite errors v_{it} and v_{is} does not depend on the difference between t and s:

$$Corr(v_{is}, v_{it}) = \sigma_\alpha^2 / (\sigma_\alpha^2 + \sigma_u^2) \geq 0, \ \ t \neq s \tag{48}$$

According to equation (48) and the assumption of consistent estimators of σ_α^2 and σ_u^2, the equation can be rewritten as:

$$\hat{\Omega} \equiv \hat{\sigma}_u^2 I_T + \hat{\sigma}_\alpha^2 j_T j_T^{'} \tag{49}$$

Then the random effects estimator can be defined (see Wooldridge (2001)):

$$\hat{\beta}_{RE} = (\sum_{i=1}^{N} X_i^{'} \hat{\Omega}^{-1} X_i)^{-1} (\sum_{i=1}^{N} X_i^{'} \hat{\Omega}^{-1} y_i) \tag{50}$$

This paper presents two different approaches to estimate which model is better suited for the panel data. The first step is to use the Least-Square Dummy variable model, adding time series dummy and cross-section dummy variables individually, and cross-section with time-series dummy variables in the cost function. This step will restructure the translog cost function form and obtain the Durbin-Watson Estimation and R^2 (coefficient of determination) value. The second step is to apply the random effects model to calculate the R^2 and Durbin-Watson values. Comparing the results of both models allows the selection of the best model. Filippini (1999) examines costs in the Swiss nursing home industry. He considers estimation of a translog cost function form employing panel data. He uses R^2 and Durbin-Watson estimators to choose the fixed effects approach. Another estimation approach is to apply the Hausman specification test to choose the suitable panel data approach.

3.6. Hausman Specification Test

Hausman (1978) describes a test based on the difference between the random effects and fixed effects approaches. Here, the simplest panel data model is written as:

$$y_{it} = X_{it}\beta + \alpha_i + \varepsilon_{it} \tag{51}$$

The fixed effects estimator $\hat{\beta}_{FE}$ is consistent when α_i and x_{it} are correlated, but random effects is inconsistent, a statistically significant difference is interpreted as evidence against the random effects assumption $E(\alpha_i|x_i) = E(\alpha_i) = 0$.

The natural test of the null hypothesis of independent, α_i's will be designed as the difference between the two estimators, $\Delta = \hat{\beta}_{FE} - \hat{\beta}_{GLS}$. If no misspecification estimator exists, then Δ should be equal to zero (see Wooldridge (2001)).

If all the assumptions are correct, then:

$E(\varepsilon_{it}|x_i, \alpha_i) = 0, t = 1, \ldots\ldots T$

$E(\alpha_i|x_i) = E(\alpha_i) = 0$ where $x_i \equiv (x_{i1}, x_{i2}, \ldots\ldots x_{it})$.

$E(X_i'\Omega^{-1}X_i) = K$

$E(\varepsilon_i\varepsilon_i'|x_i, \alpha_i) = \sigma_\varepsilon^2 I_T$ and $E(\alpha_i^2|x_i) = \sigma_\alpha^2$

assuming all assumptions hold, the case can then be estimated by using fixed effects and random effects. Then we can find these results:

$$A\operatorname{var}(\hat{\beta}_{FE}) = \sigma_\varepsilon^2[E(\ddot{X}_i'\ddot{X}_i)]^{-1}/N \tag{52}$$

$$A\operatorname{var}(\hat{\beta}_{RE}) = \sigma_\varepsilon^2[E(\tilde{X}_i'\tilde{X}_i)]^{-1}/N \tag{53}$$

where the tth row of $\ddot{X}_i$ is $x_{it} - \bar{x}_i$ and the tth row of $\tilde{X}_i$ is $x_{it} - \lambda\bar{x}_i$.

From which it follows that $\left[A\operatorname{var}(\hat{\beta}_{RE})\right]^{-1} - \left[A\operatorname{var}(\hat{\beta}_{FE})\right]^{-1}$ is positive definite, implying that $A\operatorname{var}(\hat{\beta}_{FE}) - A\operatorname{var}(\hat{\beta}_{RE})$ is positive definite. Since $\lambda \to 1$ as $T \to \infty$, these expressions show that the asymptotic variance of the RE estimator tends to that of FE as

T gets large.

Let $\hat{\delta}_{RE}$ be the vector of random effects estimates without the coefficients on time-constant variables, and let $\hat{\delta}_{FE}$ denote the corresponding fixed effects estimates. Now the Hausman test can be written as follows:

$$H = (\hat{\delta}_{FE} - \hat{\delta}_{RE})'[A\hat{\text{var}}(\hat{\delta}_{FE}) - A\hat{\text{var}}(\hat{\delta}_{RE})]^{-1}(\hat{\delta}_{FE} - \hat{\delta}_{RE}) \qquad (54)$$

is distributed asymptotically as χ^2_M under all above assumptions. The usual estimator of $A\text{var}(\hat{\delta}_{FE})$ and $A\text{var}(\hat{\delta}_{RE})$ can be used in equation (54), but if different estimates of σ^2_u are used, the matrix $A\text{var}(\hat{\delta}_{FE}) - A\text{var}(\hat{\delta}_{RE})$ need not be positive definite. Thus, it is best to use either the fixed effects estimate or the random effects estimate of σ^2_u. Let δ be the element of β that we wish to use in this test.

3.7 The Seemingly Unrelated Regression (SUR) Procedure

Under the assumptions of the classical normal regression model, the least squares estimators of the regression coefficients are unbiased and efficient. If some other piece of information that has not been taken into account, the result concerning with the properties of the least squares estimators can no longer be considered. One useful additional piece of information would be that the disturbance in the regression equation under consideration is correlated with the disturbance in some other regression equations. In addition, the imposition of regularity conditions and attendant cross-equation restrictions will also tend to affect the observable error processes, inextricably linking the disturbance terms. The population model is a set of G linear equations

$$\begin{aligned} y_1 &= X_1\beta_1 + e_1 \\ y_2 &= X_2\beta_2 + e_2 \\ &\cdot \\ &\cdot \\ y_G &= X_G\beta_G + e_G \end{aligned} \tag{55}$$

Where x_g is $1\times K_g$ and β_g is $K_g\times 1$, g=1,2,...,G. X_g is the same for all g, but the general model allows the elements and the dimension of x_g to vary across equations.

Following Zellner (1962) procedure, I assume in terms of the equation errors, that

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_g \end{bmatrix} = \begin{bmatrix} X_1 & 0 & . & . & 0 \\ 0 & X_2 & . & . & 0 \\ \cdot & \cdot & & & \cdot \\ \cdot & \cdot & & & \cdot \\ 0 & 0 & . & . & X_g \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \cdot \\ \cdot \\ \beta_g \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ e_g \end{bmatrix} \tag{56}$$

Thus, y_1 and X_1 contain all T observations on the dependent and explanatory variables in Equation 1; y_2 and X_2 contain all T observations on the dependent and explanatory variables in Equation 2; and y_g and X_g contains all T observations on the dependent and explanatory variables in Equation G. Similarly, $\beta_1, \beta_2, \ldots$ and β_g are the (k x 1) unknown coefficient vectors for each of the equations, while e_1, $e_1, \ldots e_g$ are the corresponding (T x 1) equation error vectors.

There are four assumptions for the SUR estimation procedure.

1. All errors have a zero mean:

$$E[e_i]=0 \quad \text{for } i=1,2,3;\text{t=1,2,......T} \tag{57}$$

2. In a given equation, the error variance is constant over time, but each equation can have a different variance:

$$\begin{aligned} \operatorname{var}(e_{it}) &= E\left[e_{1t}^2\right]=\sigma_{11}=\sigma_1^2 \\ \operatorname{var}(e_{2t}) &= E\left[e_{2t}^2\right]=\sigma_{22}=\sigma_2^2 \\ \ldots \quad . \quad . \quad . \quad \ldots. \\ \operatorname{var}(e_{gt}) &= E\left[e_{gt}^2\right]=\sigma_{gg}=\sigma_g^2 \end{aligned} \text{, for all t=1,2,......T} \tag{58}$$

3. Two errors that are in different equations but correspond to the same time period are correlated (contemporaneous correlation):

$$\operatorname{cov}(e_{it},e_{jt})=E\left[e_{it}e_{jt}\right]=\sigma_{ij}; \quad \text{for } i,j=1,2,\ldots,g$$

4. Errors in different time periods, whether they are in the same equation or not, are uncorrelated (autocorrelation does not exist):

$$\operatorname{cov}(e_{it,}e_{js})=E\left[e_{it}e_{js}\right]=0; \quad \text{for } t\neq s \quad \text{and} \quad i,j=1,2,\ldots,g$$

In matrix notation, these assumptions may be written compactly as

$$E[e_i]=0 \quad \text{and} \quad E\left[e_ie_j^{'}\right]=\sigma_{ij}I; \quad \text{for } i,j=1,2,\ldots,g$$

where

$$E\left[ee'\right]=E\left[\begin{bmatrix} e_1 \\ e_2 \\ . \\ . \\ e_g \end{bmatrix}\begin{bmatrix} e_1' & e_2' & . & . & e_g' \end{bmatrix}\right]=\begin{bmatrix} E[e_1e_1'] & E[e_1e_2'] & . & . & E\left[e_1e_g'\right] \\ E[e_2e_1'] & E[e_2e_2'] & . & . & E\left[e_2e_g'\right] \\ . & . & . & . & E\left[e_3e_g'\right] \\ . & . & . & . & . \\ E\left[e_ge_1'\right] & E\left[e_ge_2'\right] & . & . & E\left[e_ge_g'\right] \end{bmatrix}$$

$$=\begin{bmatrix} \sigma_{11}I_T & \sigma_{12}I_T & . & \sigma_{1g}I_T \\ \sigma_{12}I_T & \sigma_{22}I_T & . & \sigma_{23}I_T \\ . & . & . & . \\ \sigma_{1g}I_T & \sigma_{2g}I_T & . & \sigma_{gg}I_T \end{bmatrix}=\Omega=V(e) \tag{59}$$

Therefore, this equation, together with all assumptions about X and e, can be viewed as a general linear regression model. The best linear unbiased estimator of β for this model is given by Aitkin generalized least squares formula as:

$$\hat{\beta}=(X'\Omega^{-1}X)^{-1}(X'\Omega^{-1}y) \tag{60}$$

Then the variance-covariance matrix of the estimator $\hat{\beta}$ is easily shown to be $(X'\Omega^{-1}X)^{-1}$ or

$$V(\hat{\beta})=\begin{bmatrix} \sigma^{11}X_1'X_1 & \sigma^{12}X_1'X_2 & . & . & \sigma^{1g}X_1'X_g \\ \sigma^{21}X_1'X_1 & \sigma^{22}X_2'X_2 & . & . & \sigma^{2g}X_2'X_g \\ . & . & . & . & . \\ . & . & . & . & . \\ \sigma^{g1}X_m'X_1 & \sigma^{g2}X_g'X_2 & . & . & \sigma^{gg}X_g'X_g \end{bmatrix} \tag{61}$$

In practice, when we predict economic relations, the variances and covariances are unknown and must be estimated. To obtain these estimates, we should first estimate each equation by its least squares.

$$\beta_i = (X_i'X_i)^{-1}X_i'y_i \quad \text{for} \quad i = 1,2,3 \tag{62}$$

Therefore, one can obtain the least squares residuals

$$\hat{e}_i = y_i - X_i\beta_i \qquad \text{for} \quad i = 1,2,3 \tag{63}$$

Consistent estimations of the variances and covariance are given by:

$$\hat{\sigma}_{ij} = \frac{1}{T}\hat{e}_i'\hat{e}_j = \frac{1}{T}\sum_{t=1}^{T}\hat{e}_{it}\hat{e}_{jt} \quad \text{for} \quad i,j = 1,2,3 \tag{64}$$

Next, if $\hat{\Omega}$ is set as the matrix Ω with the unknown σ_{ij} replaced by estimating $\hat{\sigma}_{ij}$, then the estimated generalized least squares estimator for β can be written as

$$\tilde{\beta} = (X'\hat{\Omega}^{-1}X)^{-1}X'\hat{\Omega}^{-1}y$$

$$= \left[\begin{pmatrix} X_1 & 0 & 0 \\ 0 & X_2 & 0 \\ 0 & 0 & X_g \end{pmatrix}' \begin{bmatrix} \hat{\sigma}_{11}I_T & \hat{\sigma}_{12}I_T & \hat{\sigma}_{1g}I_T \\ \hat{\sigma}_{21}I_T & \hat{\sigma}_{22}I_T & \hat{\sigma}_{2g}I_T \\ \hat{\sigma}_{g1}I_T & \hat{\sigma}_{g2}I_T & \hat{\sigma}_{gg}I_T \end{bmatrix}^{-1} \begin{pmatrix} X_1 & 0 & 0 \\ 0 & X_2 & 0 \\ 0 & 0 & X_g \end{pmatrix}\right]^{-1}$$

$$\times \begin{pmatrix} X_1 & 0 & 0 \\ 0 & X_2 & 0 \\ 0 & 0 & X_g \end{pmatrix}' \begin{bmatrix} \hat{\sigma}_{11}I_T & \hat{\sigma}_{12}I_T & \hat{\sigma}_{1g}I_T \\ \hat{\sigma}_{21}I_T & \hat{\sigma}_{22}I_T & \hat{\sigma}_{2g}I_T \\ \hat{\sigma}_{g1}I_T & \hat{\sigma}_{g2}I_T & \hat{\sigma}_{gg}I_T \end{bmatrix}^{-1} \begin{pmatrix} y_1 \\ y_2 \\ y_g \end{pmatrix} \tag{65}$$

Following the econometric literature of SUR model, this study describes the background and brief explanations of the Norwegian fishery data.

IV. Data Source and Explanations

This research examines the annual survey data of eleven boats over the five year period. Annual observations on output level and quantity are available at the boat level; as is information about expenditure on fuel, bait, insurance, provisions, maintenance of vessels and gears, miscellaneous costs, labour costs, and the costs of capital. Table 1 lists the following key variables: average values of fish harvesting, average quantities of fish harvesting, average working days, and total costs.

Table 1: Summary Statistics of Several Key Variables

Year	Average Value[12]	Average Harvest Quantity[13]	Average Days in operation/year	Costs[14] (Norwegian Kroner)
1995	18,216,702	3,522,841.8	299	467.602.4
1996	15,646,097	3,194,076	276	370,975.6
1997	15,326,999	2,836,322.1	257	382,880.1
1998	18,990,651	2,349,023.5	286	442,194.3
1999	15,758,066	1,745,625.1	250	38,7148.5

Table 1 shows the average harvest quantities, average operation days and the total

[12] Norwegian Krone.
[13] Tonnes
[14] Total cost is equal to the sum result of labour cost, cost of capital, cost of fuel and the cost of miscellaneous expenditures.

costs reach the highest level in 1995. The average harvesting value arrived at the highest value (18,990,651 NOK) in 1998. Interestingly, we find that total costs did not arrive at the lowest level in 1999, although the Norwegian Cod fishery has the minimum operation days (250 days) in this year. Moreover, the value defined as the average value divided by the average harvest quantity reached the highest level. Hence, the average harvesting values of the Cod fishery did not decreased to the lowest level, even though the average harvesting quantity reached the lowest level (1,745,625.1 tonnes) in 1999. According to this reason, we can explain that the average values of harvesting in 1997 have the lowest values (15,326,999 NOK) with 2,836,322.1 tonnes of average harvest quantities.

The cost function is modelled on four input expenditure variables (e.g., labour, capital, fuel and miscellaneous expenditures), and one fixed output aggregate commodity. The price index of labour (w_l) is defined as an annual labour costs (payment to crew) divided by the man-years of employment. The price index for capital (w_k) is defined as the replacement value of the vessel multiplied by the total values of the interest rate plus vessel depreciation. The depreciation rate of the vessel is set at 10% and the interest rate is set at 3% over the inter-bank market rate[15] (Asche, Bjørndal and Gordon (2003). The price index of fuel is defined as the actual fuel consumption divided by the value of total vessel tonnage multiplied by operation days. The value price index of fuel is the index

[15] The inter bank rate is employed as the base rate on loans to the fishing industry as well as most other industries. For different industries one then adds a premium, which for fishing vessels normally is 3%.

that measures the consumption of fuel per vessel tonnage in every operation day. The price index of the miscellaneous expenditures (w_m) is defined as the expenditure on maintenance expenditures divided by operating days. It means that the price index of miscellaneous is the consumption of miscellaneous for every working day. Therefore, all price indices are based on the every day's consumption level. The total costs will be calculated as the sum of expenditures on labour, capital, fuel, and maintenance expenditure.

Although the vessels in the fishery catch a variety of white fish species, mainly cod fish, the cost function is based on aggregate catch levels. (Asche, Bremnes, and Wessells (1999), show that with a highly integrated market, the generalized composite commodity theorem of Lewbel (1996) will hold. A group of outputs can be modeled as a single commodity if each commodity owns the same property. Gordon and Hannesson (1996), Asche and Hannesson (1997), and Asche, Gordon and Hannesson (2002) apply for a single commodity to estimate whitefish markets. Their results show that a highly integrated market exists for whitefish. Based on this paper, it is reasonable to define a single aggregate output to be used in the cost function.

TABLE 2: Basic Statistic Results of Variables for the Cost Function

Variable	Mean	Standard error	Minimum	Maximum
Total Cost (Norwegian Krone[16])	1.74×10^7	3,575,044	1.14×10^7	2.89×10^7
Capital (Norwegian Krone)	6,451,308	1,328,378	4,624,127	1.03×10^7
Price index of labour	365,038.6	82,935.08	244,510.5	681,829.7
Price index of capital	10,969.053	2,267.362	7,224.792	17,409.672
Price index of miscellaneous	15,896.8	4,695.87	9,006.044	33,797.76
Price index of fuel	9.505	1.692	5.473	13.815
Output (tonnes)	2,729,578	896,579	1,358,496	5,285,100
Cost share of labour	0.294	0.038	0.206	0.386
Cost share of capital	0.373	0.051	0.265	0.492
Cost share of miscellaneous	0.245	0.043	0.171	0.343
Cost share of fuel	0.088	0.015	0.059	0.124

The values used in statistic are shown in Table 2. The cost shares of labour, capital, miscellaneous expenditures and fuel are presented in Table 2. Other basic parameters such as total costs, capital, output quantities and the price index of labour, capital, fuel, miscellaneous expenditures are shown in Table 2.

Table 3. Tonnage Level of Each Boat

[16] 1 NOK=$0.1889 CDN (Bank of canada March 26)

Boat Number	1	2	3	4	5	6	7	8	9	10	11
Tonnage (tonnes)	576	549	435	549	1199	609	592	529	526	527	610

In Table 3, the tonnage of each boat is presented. Boat Number Three has the lowest tonnage in eleven boats. Table 3 shows that Boat Number Five is the biggest boat (1199 tonnes)and Boat Number Three is the smallest one (435 tonnes).

Some interesting characters of the data set are provided in Figure 1, 2, 3, 4, 5, 6 and 7. Figure 1 shows the fishery output quantities. Figure 2 shows the fishery output values.

Figure 1: Fishery Harvest Quantity

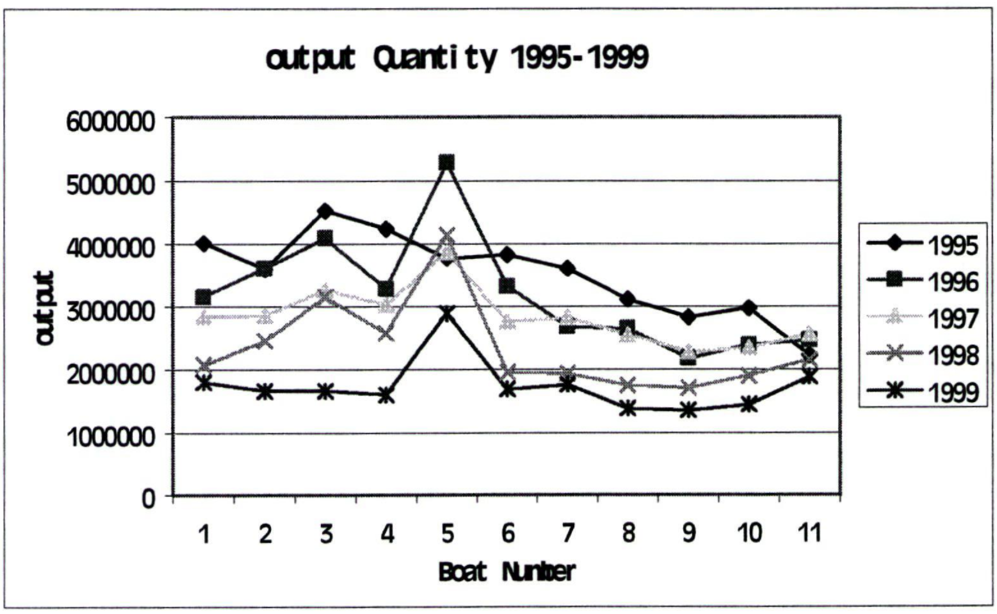
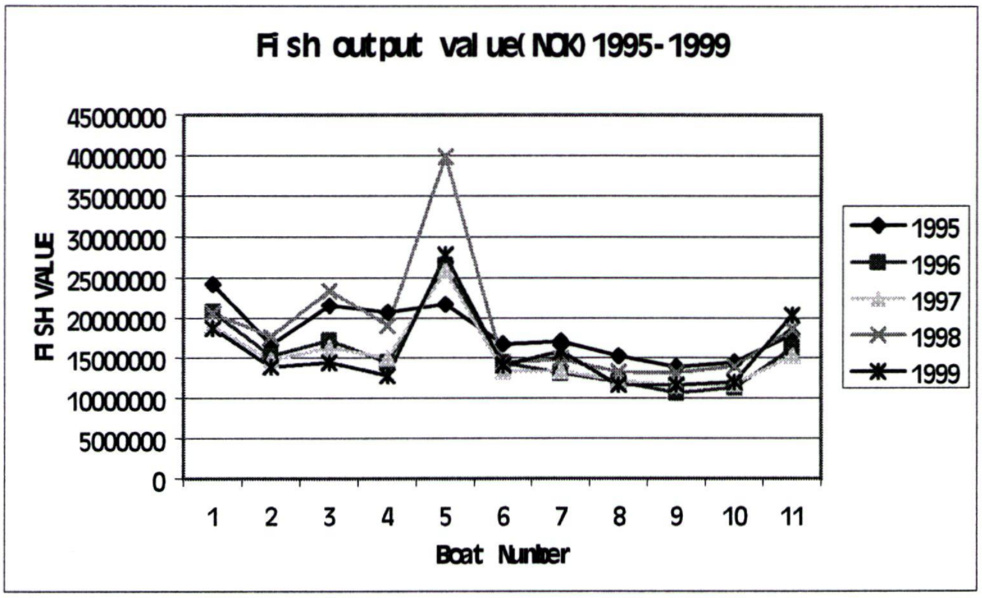


Figure 2: Fishery Output Value



In Figures 1 and 2, the variations of fish output quantity, and the harvesting value of each boat (cross-sectional unit) with time are observed. Interestingly, Boat Number Five generally reaches the maximum fish outputs and harvesting values of the other ten boats combined in the four year period (from 1996 to 1999).

Figure 3-6 display the characters of labour cost, capital cost, miscellaneous cost and fuel cost in the data set. In these figures, Boat Number Five had possessed the highest capital, fuel costs from 1995 to 1999. Costs of miscellaneous expenditure and labour do not own this property.

Figure 3: Labour Cost

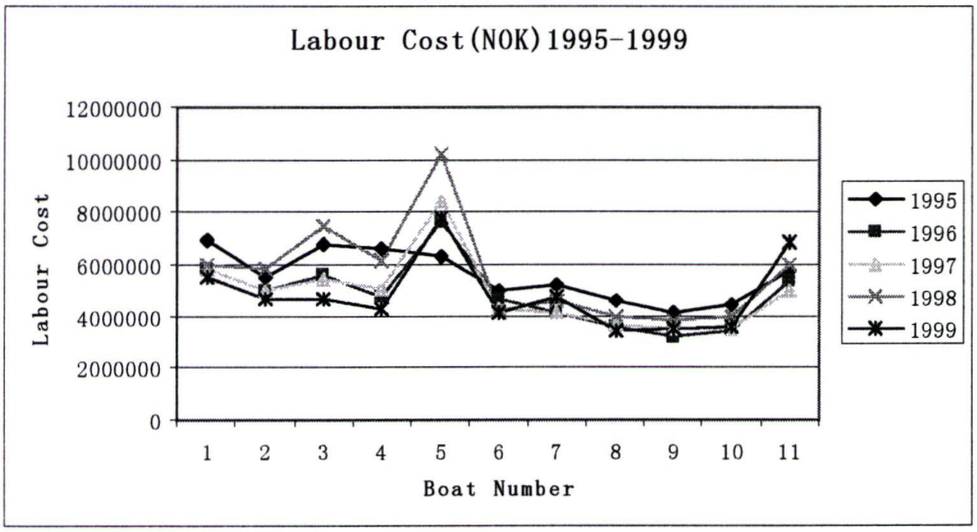


Figure 4: Cost of Capital

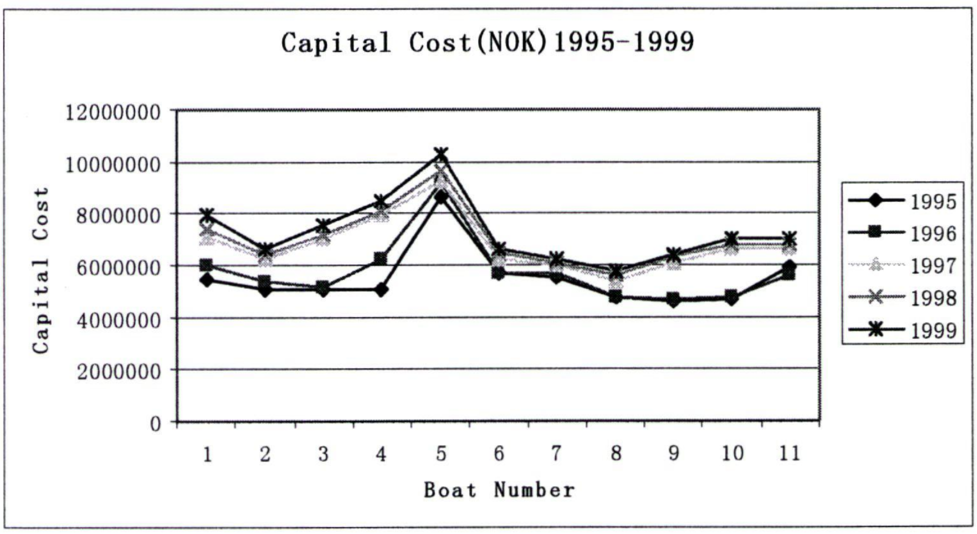


Figure 5: Miscellaneous Cost

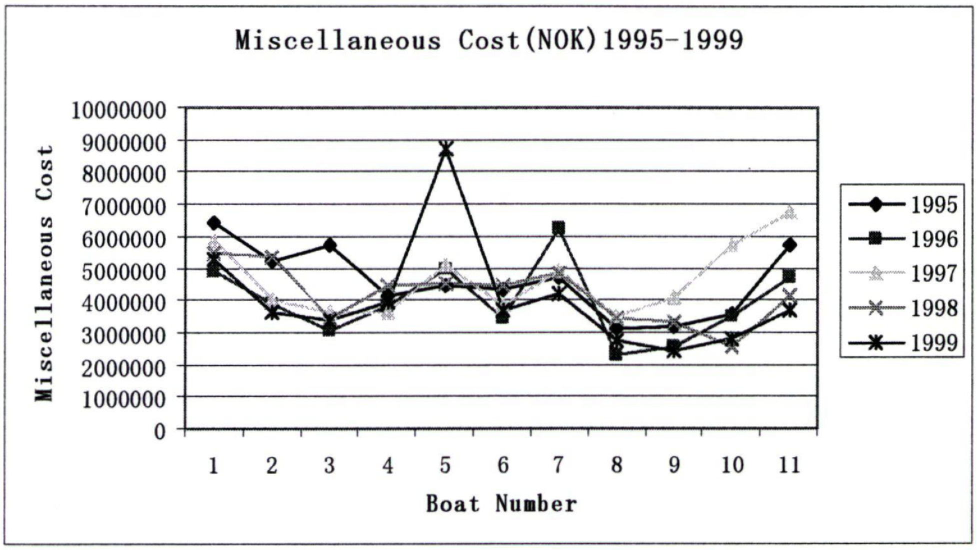


Figure 6: Fuel Cost

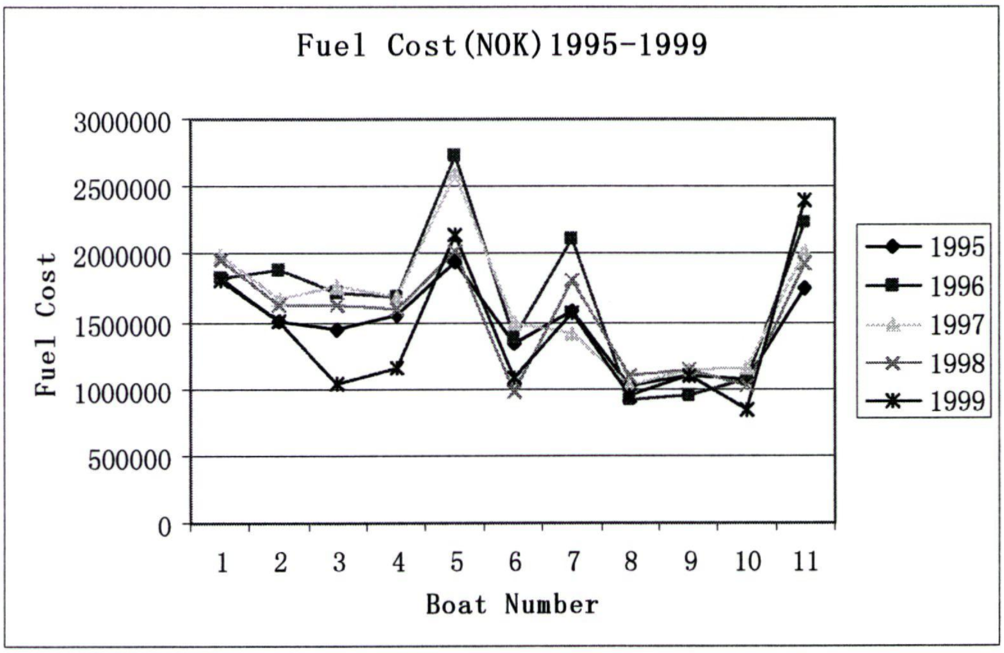
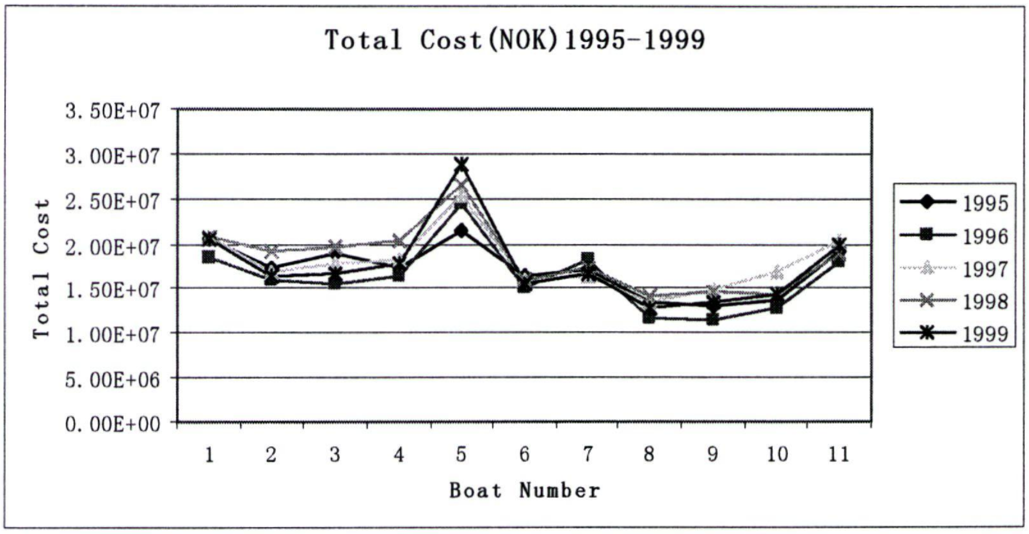


Figure 7: Total Costs incurred from 1995 to 1999



The characters of total costs are shown in Figure 7. Boat Number Five characterizes the highest level of total costs in the Norwegian Cod fishery since of the highest labour costs, capital costs, and fuel costs in a five year period.

V. Empirical Results

In the first part of this chapter, we use the Hausman specification test to compare the fixed effects with the random effects approaches and to select the appropriate panel data approach. Then, the Seemingly Unrelated Regression procedure mixed with the fixed effects approach are employed to examine the dual cost function form and to obtain the Allen elasticities of substitution, own-price elasticities under both the long-run and short-run model respectively. Afterwards, we utilize a Kulatilaka test to choose the short-run equilibrium or the long-run equilibrium model. Following this test, economies of scale of the long-run model is measured.

5.1 Econometric Estimation process of Hausman specification Test

The fixed effects approach is one of the panel data approaches used to control omitted variables when the omitted variables change over time but do not vary across cross-section units or those variables only change across cross-section units but keep constant over time. At the beginning of the fixed effects regression, the study only adds $t-1$ time dummy variables into the equation (66)[17].

[17] Equation (66) is present in Appendix C

The estimated R^2 value of the fixed effect model is 0.955 and the value of F[18] test for all residuals u_i is equal to 14.48, for which degrees of freedom are 10 and 24. Meanwhile, the value of F test to estimate the relationship of all time series dummy variable effects is only 0.51, at which the degrees of freedom are 10 and 24. in those estimates, F value indicates that the null hypothesis has no reason to be rejected that all joint effects of year dummy variables are equal to zero.

Following the fixed effects estimation model, we estimate the random effects approach. We do not add the time dummy variables into the translog cost function when we estimate the random effects approach. According to the R^2 parameter of the random effects model, the within estimator performs worse than the within estimator of fixed-effects estimator, and better than the between and overall estimators. The 95% chi-squared value χ^2 for the twenty degrees of freedom of the random effects estimator is 483.94, which is greater than the critical value that the coefficients are significant. Finally, the Hausman specification test is examined. The alternative hypothesis is that the fixed effects estimation is suitable and the random effects estimation is not. The null hypothesis is that the two estimation methods are both correct. The 95% chi-squared value χ^2 of the Hausman specification test ($\chi^2 = (b-B)'[V(b)-V(B)]^{-1}(b-B)$) at twenty degrees of freedom is equal to 1845.80, where the null hypothesis should be

[18] in this thesis, all significance levels are set at 5%

rejected. Therefore, the fixed effects regression model should be selected when a set of time dummy variables in the regression function are added.

In the next step, we only add the $n-1$ cross-section dummy variables to the equation (66), the within R^2 value of the random effects model is 0.950, and the F value for degrees of freedom ten and twenty-four for all residuals u_i is equal to 0 which is less the critical value. Using the random effects regression model, the R^2 parameter performs worse within than the within/fixed-effects estimator, and better than the between and overall estimators. The 95 % chi-squared χ^2 of the random effects model for twenty degrees of freedom is 483.94. When considered together, the coefficients are significant. Applying the Hausman specification test, the ninety-five percent chi-squared value for twenty degrees of freedom $(\chi^2=(b-B)'[V(b)-V(B)]^{-1}(b-B))$ is -18.49. The negative result shows that we cannot reject the null hypothesis and the fixed-effects and random-effects estimation models are both correct.

Finally, this study adds all (n-1) cross-section and (t-1) time binary variables in the equation (66) to model the fixed effects assumption. Using the Hausman specification estimation method, the 95% chi-squared value for twenty degrees of freedom $(\chi^2=(b-B)'[V(b)-V(B)]^{-1}(b-B))$ is equal to 1845.84, which is so great that the null hypothesis can be rejected. Therefore, fixed effects approach with time series and cross-section dummy variables is appropriate.

Consequently, according to those above procedures, the fixed effects model is suitable for the long-run model.

If the fixed effects model is used in the short-run translog cost function, we add n-1 cross-section and t-1 dummy variables into the function form and set the input factor of capital as a fixed variable. We find that the R^2 of the fixed effects model at within is 0.9131, the between value of R^2 of the fixed effects model is 0.9530 and the overall R^2 value is 0.9087. The F value for the degrees of freedom twenty and twenty-four is 9.60, which is greater than the critical F value at 5% significance level. Afterwards, the random effects approach is used to analyze the short-run translog cost function, the R^2 value of the random effects model at within changes to 0.865, while the between value of R^2 and the overall value of R^2 increase to 0.983 and 0.960 respectively. The Hausman specification test is estimated in the next procedure. According to the estimates, we find that the ninety-five percent chi-squared value χ^2 for the twenty degrees of freedom ($\chi^2 = (b-B)'[V(b)-V(B)]^{-1}(b-B)$) is equal to 7.52. This result indicates that the fixed effects model is suitable for analyzing this short-run model.

Therefore, the fixed effects approach can be used in both long-run and short-run

Therefore, the fixed effects approach can be used in both long-run and short-run model according to the above results.

5.2 Estimated Results of Both the Long-Run and Short-Run Models

Following the iterative Zellner (1962) technique of the Seemingly Unrelated Regression procedures, this thesis will analyze the multivariate system of the long-run and the short-run translog cost function form with the cost share equations. The estimated disturbance covariance matrix required to implement Zellner procedure is singular because the disturbances on the share equations must sum to zero for each boat. This thesis drops one of the share equations from the multivariate system. Based on the SUR regression procedures and the fixed effects approach, the estimated parameters of the long-run model are provided in Table 4 and Table 5[19].

In the first estimation procedure, this thesis applies the long-run translog cost function form to model and estimate the technical structures of the Norwegian cod fishery. Four inputs, capital (K), labour (L), fuel (F) and miscellaneous expenditure (M) and the output (Y) are employed in this study. $P_{sk,t}$ is the price index of the capital to Boat Number s at the time period t; $P_{sl,t}$ is the price index of the labour to boat s at the time

[19] The model has been estimated using the computer program STATA 8.0.

period t; $P_{sf,t}$ is the price index of the fuel to Boat Number s at the time period t and $P_{sm,t}$ is the price index of the miscellaneous material to Boat Number s at the time period t. At the same time, there are one output (Y_{st}), and share equations of capital, labour, fuel and miscellaneous material. By definition, $S_M + S_K + S_L + S_F = 1$. The translog cost function with the cost share function forms are presented in the Appendix C.

In the translog cost function and the cost share function forms, the errors u_{ig} can affect production but are unobserved. For the Seemingly Unrelated Regression procedures, this study assumes that:

$E(u_i | \ln\_p_i, \ln\_y_i) = 0$

where $u_i \equiv (u_{sf}, u_{sL}, u_{sk}, u_{sM})'$ and $\ln\_p_i \equiv (\ln\_pl_{st}, \ln\_pk_{st}, \ln\_pm_{st}, \ln\_pf_{st})$ because the cost shares must sum to unity for each share factor, $\alpha_L + \alpha_m + \alpha_k + \alpha_f = 1$, $\sigma_{LK} + \sigma_{LM} + \sigma_{LF} + \theta_{LL} = 0$, $\sigma_{LK} + \sigma_{KM} + \sigma_{KF} + \theta_{KK} = 0$, $\sigma_{LM} + \sigma_{KM} + \sigma_{MF} + \theta_{MM} = 0$, $\sigma_{LF} + \sigma_{KF} + \sigma_{MF} + \theta_{FF} = 0$, and $\beta_{YL} + \beta_{YK} + \beta_{YM} + \beta_{YF} = 0$, $u_{SL} + u_{sK} + u_{sm} + u_{SF} = 0$. The last restriction implies that $\Omega = \mathrm{var}(u_i)$ has Rank Three. Therefore, one of the share equations (S_f) is dropped, and only the share equations for labour, capital and miscellaneous material with the translog cost function are analyzed. The results from the Seemingly Unrelated Regression procedures are more efficient than estimations only use a single equation to analyze the panel data fixed effect model.

This study employs capital as the fixed variable in the short-run model. Under the short-run model, the equation (66)[20] only has three price indices with mean value: the price index of labour, the price index of miscellaneous, and the price index of fuel. The fixed variable of capital and the output variable of the fishery do exist in equation (66). In addition to the short-run translog cost function, relative cost share functions of labour, miscellaneous are added to analyze the short-run SUR model. This study adds the $\ln\_fk_{st}$ instead of the input factor $\ln\_pk_{st}$ into the equations (67) and (69). The estimated parameters under the short-run model are presented in Table 4 and Table 6.

Table 4: R^2 between Long-run and Short-run SUR models

	Short-run SUR model	Long-run SUR model
Total cost function	0.938	0.979
Cost share function of labour	0.889	0.892
Cost share function of miscellaneous	0.687	0.584
Cost share of function of capital	N/A	0.565

In Table 4, the R^2 of the short-run trans-log cost function is only 0.938 and the R^2

[20] Equation (66)-equation (70) are presented in Appendix C

of cost share function of Labour, Miscellaneous are 0.889 and 0.687. The results of R^2 values for the long-run cost equation and labour, miscellaneous and capital share equations are calculated to be 0.979, 0.892, 0.584 and 0.565. By comparing R^2 values, the long-run SUR procedure is better than the short-run SUR procedure.

Table 5: Total Cost Parameter Estimates[21] (Standard Errors in Parentheses) Under the Long-run Model

Parameters		Parameters	
Constant α_0	16.701 (0.0151)	θ_{LL}	0.118 (0.009)
α_y	0.195 (0.031)	θ_{KK}	0.103 (0.017)
α_L	0.294 (0.002)	θ_{MM}	0.122 (0.010)
α_K	0.372 (0.004)	θ_{FF}	0.070 (0.009)
α_M	0.247 (0.004)	Year 1996	**-0.011** **(0.011)**
α_F	0.087 (0.002)	Year 1997	**-0.013** **(0.012)**
β_{YL}	0.021 (0.007)	Year 1998	**0.046** **(0.017)**
β_{YK}	-0.058 (0.015)	Year 1999	**0.050** **(0.025)**
β_{YM}	0.035 (0.012)	Boat 2	-0.035 (0.015)
β_{YF}	0.002 (0.007)	Boat 3	**-0.155** **(0.017)**
σ_{LK}	-0.032 (0.008)	Boat 4	-0.054 (0.015)

[21] denotes significance level at 5% level

σ_{LM}	-0.095 (0.005)	Boat 5	**0.203** **(0.018)**
σ_{LF}	0.009 (0.006)	Boat 6	-0.068 (0.015)
σ_{KM}	-0.010 (0.012)	Boat 7	-0.059 (0.015)
σ_{KF}	-0.061 (0.008)	Boat 8	-0.124 (0.016)
σ_{MF}	-0.018 (0.005)	Boat 9	-0.123 (0.018)
θ_{YY}	0.097 (0.074)	Boat 10	-0.127 (0.016)
		Boat 11	**0.0712** **(0.016)**

Table 6: Total Cost Parameter Estimates[22] (Standard Errors in Parentheses) Under the Short-run Model

Parameters		Parameters	
Constant α_0	16.312 (0.036)	θ_{LL}	0.120 (0.013)
α_y	0.334 (0.059)	θ_{KK}	-0.911 (0.631)
α_L	0.294 (0.002)	θ_{MM}	0.138 (0.013)
α_K	N/A	θ_{FF}	0.114 (0.223)
α_M	0.247 (0.003)	Year 1996	**-0.093** **(0.024)**
α_F	0.459 (0.004)	Year 1997	**-0.089** **(0.027)**
β_{YL}	0.037 (0.006)	Year 1998	**0.074** **(0.033)**

[22] denotes significance level at 5% level

β_{YK}	-0.060 (0.220)	Year 1999	**0.093** **(0.045)**
β_{YM}	0.051 (0.011)	Boat 2	-0.056 (0.027)
β_{YF}	-0.088 (0.013)	Boat 3	-0.095 (0. 051)
σ_{LK}	-0.043 (0.012)	Boat 4	-0.055 (0.031)
σ_{LM}	-0.072* (0.007)	Boat 5	**0.212** **(0.051)**
σ_{LF}	-0.047 (0.011)[a]	Boat 6	-0.124 (0.027)
σ_{KM}	-0.086 (0.020)	Boat 7	-0.132 (0.028)
σ_{KF}	0.129 (0.026)	Boat 8	-0.147 (0.030)
σ_{MF}	-0.066 (0.017)	Boat 9	-0.185 (0.032)
θ_{YY}	-0.148 (0.226)	Boat 10	-0.150 (0.030)
		Boat 11	**0.059** **(0.030)**

Table 5 shows that t values of the coefficients of time dummy variables are greater than the critical value. For example, the estimated t-values of the time series dummy variables year 1998 and 1999 are 2.79 and 2.05 respectively. Hence, the null hypothesis should be rejected at the degrees of freedom 54, that is, the years 1998 and 1999 will have a positive effect on the total costs. On the other hand, the negative coefficients of time series dummy variables including the year 1996 and 1997 have a negative effect on the total costs. In this study, we also find that the coefficients of cross-sectional dummy variables for Boat Number Two, Boat Number Three, Boat Number Four, Boat Number Six, Boat Number Seven, Boat Number Eight and Boat Number Nine are all negative. Meanwhile, their absolute t values are greater than the critical t value at the 95% level. In the fishery, the total costs fall with the increasing fish harvesting of Boat Number Two, Boat Number Three, Boat Number Four, Boat Number Six, Boat Number Seven, Boat Number Eight and Boat Number Nine when the year influence is constant. On the contrary, Boat Numbers Five and Eleven have positive coefficients, and their t values are greater than the critical t value. For Boat Numbers Five, the positive coefficient implies that increasing the catch level of Boat Number Five will increase the total costs in the constant year effect. Interestingly, one can find that the coefficient of the cross-sectional dummy variable (Boat Number Five) is the biggest value in all the positive coefficients cross-sectional binary variables. According to the parameters of Table 3 and 5, this study points out that Boat Number Five shows the multiple characteristics of having the maximum cost and the biggest tonnage. The total cost will increase to the highest level (1.225%) when Boat Number Five increases by 1% fish harvesting. Based on Table 3 and 5, the estimated parameter indicates that the total costs will decrease to 1.168% when the smallest Boat Number Three increases 1% harvest level.

Based on the parameters in Table 6, the absolute t values of the cross-sectional dummy variables and time dummy variables are greater than the critical values that the null hypothesis is rejected. Under the short-run model, the effects of years 1996 and 1997 decrease the total costs, while the effects of years 1998 and 1999 will increase the total costs. Meanwhile, increasing the catch level of Boat Number Five and Eleven will raise the total short-run costs in the constant year effect. Increasing the catch level of other boats will decrease the total short-run costs in the constant year effect.

Following the estimation procedures, this study examines the elasticities of substitution for i, j prices under both the long-run and the short-run models. The Allen partial elasticities are reported in Table 7 and 8.

Table 7: Implied Elasticities of Substitution under the Long-Run Model

	Labour	Capital	Fuel	Miscellaneous
Labour	-1.043 (0.086)			
Capital	**0.709*** **(0.028)**	-0.943 (0.371)		
Fuel	**1.344*** **(0.432)**	**-0.883*** **(0.025)**	-1.048 (0.098)	
Miscellaneous	**-0.304*** **(0.103)**	**0.892*** **(0.358)**	**0.182*** **(0.067)**	-1.271 (0.342)

* Allen partial elasticities of substitution
significance level is set at 5% level

Table 8: Implied Elasticities of Substitution under the Short-Run Model

	Labour	Capital	Fuel	Miscellaneous
Labour	-0.299 (0.025)			
Capital	N/A	N/A		
Fuel	**0.647** **(0.001)**	N/A	-0.294 (0.012)	
Miscellaneous	**0.007** **(0.002)**	N/A	**0.418** **(0.203)**	-0.194 (0.018)

* Allen partial elasticities of substitution
significance level is set at 5% level

Table 7 indicates that the parameters of capital and labour, fuel and labour, miscellaneous and capital, miscellaneous and fuel are greater than zero, which means the input factors are Allen substitutes. However, the parameters of labour and miscellaneous, capital and fuel are negative, and the negative values imply that those input factors are Allen complements. A rise in the price of labour will lead to a decreased utilization of miscellaneous materials. Also a rise in the price of fuel leads to a decreased utilization of capital. According to the estimates in Table 8, input factors of labour and miscellaneous, labour and fuel, fuel and miscellaneous are all Allen substitutes under the short-run model.

Table 9: Own Price Elasticities Comparison

	Labour	Capital	Fuel	Miscellaneous
Long-run model	-0.306 (0.024)	-0.351 (0.111)	-0.259 (0.100)	-0.111 (0.068)

Short-run model	-0.292 (0.086)	N/A	-0.294 (0.074)	-0.194 (0.057)

significance level is set at 5% level

From the information in Table 9, all own price elasticities are negative and rather inelastic under both the long-run and the short-run model.

Based on the parameters in Table 7 and 8, we find that the elasticity of Allen substitutes (fuel and miscellaneous) in the long-run model is only 0.182, which is less than the elasticity of Allen substitutes that is equal to 0.418 in the short-run model. Table 9 shows that the own-price elasticities of fuel and miscellaneous in the long-run model are less than those own-price elasticities in the short-run model. Those results implicate that the variations of miscellaneous and fuel are more flexible in the short-run model. Therefore, in the short-run model, the utilization of miscellaneous will increase more when the fuel price increases. Meanwhile, in the short-run model, the utilization of fuel also increases more with the increasing price of miscellaneous. On the other hand, either the utilizations of fuel or miscellaneous will decrease more with the rising price of itself the short-run model.

Due to the estimator of the Kulatilaka (1985) test, the test statistic χ^2_{55} is calculated to be 19.37. The 95% percent chi-squared value for 55 observations is 91.95. Therefore, the null hypothesis is not rejected at conventional significant levels. Consequently, capital is modeled as a variable input in the cost function.

Table 10: Estimation parameters of Economies of Scale

	Maximum output	Output at mean value	Minimum output
economies of scale*	0.677	0.805	0.941

* economies of scale under the long-run SUR model

Table 10 shows that all parameters of economies of scale are all positive. It means that economies of scale occur in the Norwegian cod fishery. When the fish outputs increase, the Norwegian fishery has a better chance to decrease its average costs. The value of economies of scale will increase with the falling output in the long-run model. Due to results of economies of scale, we find that the Norwegian Cod fish industry does not have race to fish under the long-run model

In conclusion, in these estimation procedures, we verify that the fixed effects approach is the appropriate panel data estimation approach in this thesis. We examine the technical structure changes and scale effects by employing both the Seemingly Unrelated Regression procedure and the fixed effects approach.

According to the SUR procedure with fixed effects approach in both the long-run and short-run models, we find the year dummy variables 1996 and 1997 have the negative effects on the total costs, whereas the year dummy variables 1998 and 1999 have the positive effects on the total costs. Meanwhile, under both models, the cross-section dummy variables Boat Five and Boat Eleven have the positive effects on the total costs. Other cross-section dummy variables have the negative effects on the total costs.

Under the long-run model, only the inputs factors of labour and miscellaneous, capital and fuel are Allen complements. Other inputs factor combinations are all Allen substitutes. On the other hand, inputs factor combinations in the short-run model are all Allen substitutes. Moreover, all own-price elasticities are negative and rather inelastic under either the long-run or the short-run model.

A Kulatilaka test is employed in this thesis. The test statistic χ^2_{55} is less than the critical χ^2 value. Hence, the null hypothesis is not rejected. Long-run cost function should be selected in modelling the fishery production structure.

Finally, all estimated parameters of economies of scale are greater than zero. These results implicate that the economies of scale occurs in the Norwegian Cod fishery.

Chapter VI: Estimates Verification

Asche, Bjorndal and Gordon (2003) examine the technical changes and the scale effects by utilizing a cross-section data set for the Norwegian Cod fishery. The objective of comparing the estimates in this study with their estimates is to testify that the panel data set is more useful in measuring and identifying changes in technology and scale effects. Meanwhile, the estimates in this thesis can verify the Norwegian Cod fishery operates under the economies of scale.

Under the long-run equilibrium model, the estimated parameters of Allen elasticities of substitution and own-price elasticities both of this thesis and those estimates reported in Asche Bjørndal and Gordon (2003) are shown in Tables 11 and 12.

Table 11: Allen Elasticities of Substitution Comparison

	Allen elasticity		**Allen elasticity****
σ_{LK}	0.709	σ_{LK}	0.342**
σ_{LF}	1.344	σ_{LF}	N/A
σ_{LM}	**-0.304**	σ_{LM}	0.070**

σ_{KF}	**-0.883**	σ_{KF}	N/A
σ_{KM}	0.892	σ_{KM}	0.448**
σ_{MF}	0.182	σ_{MF}	N/A

** Results from Asche Bjørndal and Gordon (2003)
significance level is set at 5% level

Table 12: Own-Price Elasticities Comparison

	Own-price elasticity		Own-price elasticity
Labour	-0.306	Labour	-0.163**
Capital	-0.351	Capital	-0.223**
Fuel	-0.256	Fuel	N/A
Miscellaneous	-0.111	Miscellaneous	-0.209**

** Asche Bjorndal and Gordon's results
significance level is set at 5% level

In Tables 11 and 12, we find that the heterogeneity problems based on the omitted variables are overcome in this thesis. Both scale changes (economies of scale) and technical changes (Allen elasticities of substitution and own-price elasticities) can be measured successfully. The parameters of σ_{LK}, σ_{LF}, σ_{KM} and σ_{MF} are all Allen substitutes. However, this study notices that the Allen elasticities of capital and fuel (σ_{KF}), labour and miscellaneous expenditure (σ_{LM}) are negative values. In the fishery considered, the inputs labour and miscellaneous, capital and fuel are Allen complements.

Moreover, the own-price elasticities are all negative in Table 12. The absolute values of own-price elasticities and Allen elasticities of substitution in this study are greater than those parameters reported in Asche, Bjorndal and Gordon (2003). In this thesis, we analyze the techniques of fishery by using a panel data set, which includes the time dimension. Hence, the estimates are more useful to measure the technical changes. That is the reason why all absolute values of Allen elasticities of substitution and own-price elasticities are greater in this study.

We had known that the cross-section data sets allow for measures of scale effects because scale effects vary along an average cost. Asche, Bjørndal and Gordon (2003) investigate that the Norwegian Cod fishery operates under economies of scale. The parameters in this thesis justify the results reported in Asche, Bjørndal and Gordon (2003). These results indicate that the fishermen operate under both a TAC and IVQs management regulations with no longer a race to fish.

VII. Concluding Remarks

In this thesis, several microeconomic analyzing tools, namely the duality theory, dual cost function approach and the translog function form are employed to model the production structure of the Norwegian Cod fishery. A number of econometric estimation procedures of panel data sets, which include fixed effects and random effects approaches, Hausman specification test, are utilized to justify the fixed effects model as the appropriate estimation approach in this research. Moreover, the thesis employs the Seemingly Unrelated Regression Procedures with fixed effects approach to investigate both the technical changes and scale effects of the fishery in both the long-run and short-run models.

In this case, by using fixed effects estimation approach with the Seemingly Unrelated Regression procedure, some interesting features are discovered, while econometric estimations only using time series or cross-section data cannot do that. In this research, we find that both the time series and cross-section binary variables affect the total costs.

This study examines the Allen elasticities of substitution, own-price elasticities. The empirical results indicate that all own price elasticities are negative and rather inelastic under both the long-run and short-run models. Under the short-run model, we find that all input factor combinations are Allen substitutes. However, under the long-run model, input factors of labour and miscellaneous, capital and fuel are Allen complements, although input factors of labour and capital, labour and fuel, capital and miscellaneous, miscellaneous and fuel are Allen substitutes. The estimate of the Kulatilaka (1985) test confirms the validity of the long-term equilibrium model.

Asche, Bjørndal and Gordon (2003) investigate that all input factors are Allen substitutes. Since the heterogeneity problems caused by omitted variables are solved successfully by using panel data estimation procedures, we find that all absolute values of Allen elasticities of substitution are greater in this study. Moreover, this thesis indicates that inputs labour and miscellaneous, capital and fuel are Allen complements. The own-price elasticities of all input factors in this thesis are also greater than those parameters in Asche, Bjørndal and Gordon (2003). The estimated results verify that panel data approach are useful in measuring technical changes i.e., own-price elasticities and elasticities of substitution.

The empirical results about economies of scale validate the conclusion derived from Asche, Bjørndal and Gordon (2003). In conclusion, fishermen operate under the regulated IVQs and TAC without a race to fish in the Norwegian Cod fishery. Therefore, these results confirm that panel data estimation approaches are also useful in detecting the scale effects in the fishery.

Appendix A

Shephard's Lemma: Let $x_i(w, y)$ be the firm's conditional factor demand for input i, then if the cost function is differentiable at (w, y), and $w_i > 0$ for $i = 1,\dots,n$ then

$$x_i(w, y) = \frac{\partial c(w, y)}{\partial w_i} \qquad i = 1,\dots,n$$

Proof. Let x^* be a cost-minimizing bundle that produces y at prices w^*. then define the function

$$g(w) = c(w, y) - wx^*$$

Since $c(w, y)$ is the cheapest way to produce y, this function is always nonpositive. At $w = w^*$, $g(w^*) = 0$. Since this is a maximum value of $g(w)$, its derivative must vanish:

$$\frac{\partial g(w^*)}{\partial w_i} = \frac{\partial c(w^*, y)}{\partial w_i} - x_i^* = 0 \quad i = 1,\dots,n$$

Hence, the cost-minimizing input vector is just given by the vector of derivative of the cost function with respect to the prices, that is, the cost function is by definition equal to $c(w, y) \equiv wx(w, y)$. Differentiating this expression with respect to w_i and using the first-order conditions given us the result (see Varian (1993)).

Appendix B

Envelope Theorem:

Consider an arbitrary maximization problem where the objective function depends on the same parameters α:

$$Z(\alpha) = \max_x f(x,\alpha)$$

In this case of the profit function as a function of the parameter α would be some price, x would be some factor demand, and $Z(\alpha)$ would be the maximized value of profits as a function of the price.

Let $x(\alpha)$ be the value of x that solves the maximization problem. Then we can also write $Z(\alpha) = f(x(\alpha),\alpha)$. This simply says that the optimized value of the function equals to the function evaluated at the optimizing choice.

It is often of interest to know how $Z(\alpha)$ changes as a changes. The envelope theorem tells us the answer:

$$\frac{dZ(\alpha)}{d\alpha} = \frac{\partial f(x,\alpha)}{\partial \alpha}\bigg|_{x=x(\alpha)}$$

This expression says that the derivative of Z with respect to α is given by the partial derivative of f with respect to α, holding x fixed at the optimal choice.

Let's see how the envelope theorem works in the case of a simple one-input, one-output maximization problem. The profit maximization problem is

$$\pi(p,w) = \max_x pf(x) - wx$$

The α in the envelope theorem is p or w, and $Z(\alpha)$ is $\pi(p,w)$. According to the envelope theorem, the derivative of $\pi(p,w)$ with respect to p is simply the partial derivative of the objective function, evaluated at the optimal choice:

$$\frac{\partial \pi(p,w)}{\partial p} = f(x)\big|_{x=x(p,w)} = f(x(p,w)).$$

Similarly,

$$\frac{\partial \pi(p,w)}{\partial w} = -x\big|_{x=x(p,w)} = -x(p,w).$$

Which is the profit-maximizing net supply of the factor (see Varian (1993)).

Appendix C

The translog cost function and cost share functions can be defined as:

$$
\begin{aligned}
\ln\_C = {} & \alpha_0 + \alpha_y \ln Y_{st} + \alpha_L \ln\_pl_{st} + \alpha_K \ln\_pk_{st} + \alpha_M \ln\_pm_{st} + \alpha_F \ln\_pf_{st} \\
& + \beta_{YL}(\ln\_Y_{st})(\ln\_pl_{st}) + \beta_{YK}(\ln\_Y_{st})(\ln\_pk_{st}) + \beta_{YM}(\ln\_Y_{st})(\ln\_pm_{st}) \\
& + \beta_{YF}(\ln\_Y_{st})(\ln\_pf_{st}) + \frac{1}{2}\sigma_{LK}(\ln\_pl_{st})(\ln\_pk_{st}) + \frac{1}{2}\sigma_{LM}(\ln\_pl_{st})(\ln\_pm_{st}) \\
& + \frac{1}{2}\sigma_{LF}(\ln\_pl_{st})(\ln\_pf_{st}) + \frac{1}{2}\sigma_{KM}(\ln\_pk_{st})(\ln\_pm_{st}) + \frac{1}{2}\sigma_{KF}(\ln\_pk_{st})(\ln\_pf_{st}) \\
& + \frac{1}{2}\sigma_{MF}(\ln\_pm_{st})(\ln\_pf_{st}) + \frac{1}{2}\theta_{YY}(\ln\_Y_{st})^2 + \frac{1}{2}\theta_{LL}(\ln\_pl_{st})^2 + \frac{1}{2}\theta_{KK}(\ln\_pk_{st})^2 \\
& + \frac{1}{2}\theta_{MM}(\ln\_pm)^2 + \frac{1}{2}\theta_{FF}(\ln\_pf_{st})^2 + u_{st}
\end{aligned}
\tag{66}
$$

$$
\begin{aligned}
S_L = {} & \alpha_L + \beta_{YL}(\ln\_Y_{st}) + \frac{1}{2}\sigma_{LK}(\ln\_pk_{st}) + \frac{1}{2}\sigma_{LM}(\ln\_pm_{st}) + \frac{1}{2}\sigma_{LF}(\ln\_pf_{st}) \\
& + \theta_{LL}(\ln\_pl_{st}) + u_{sL}
\end{aligned}
\tag{67}
$$

$$
\begin{aligned}
S_K = {} & \alpha_K + \beta_{YK}(\ln\_Y_{st}) + \frac{1}{2}\sigma_{LK}(\ln\_pl_{st}) + \frac{1}{2}\sigma_{KM}(\ln\_pm_{st}) + \frac{1}{2}\sigma_{KF}(\ln\_pf_{st}) \\
& + \theta_{KK}(\ln\_pk_{st}) + u_{sk}
\end{aligned}
\tag{68}
$$

$$
\begin{aligned}
S_M = {} & \alpha_M + \beta_{YM}(\ln\_Y_{st}) + \frac{1}{2}\sigma_{LM}(\ln\_pl_{st}) + \frac{1}{2}\sigma_{KM}(\ln\_pk_{st}) + \frac{1}{2}\sigma_{MF}(\ln\_pf_{st}) \\
& + \theta_{MM}(\ln\_pm) + u_{sm}
\end{aligned}
\tag{69}
$$

$$
\begin{aligned}
S_F = {} & \alpha_F + \beta_{YF}(\ln\_Y_{st}) + \frac{1}{2}\sigma_{LF}(\ln\_pl_{st}) + \frac{1}{2}\sigma_{MF}(\ln\_pm_{st}) + \frac{1}{2}\sigma_{KF}(\ln\_pk_{st}) \\
& + \theta_{FF}(\ln\_pf_{st}) + u_{sf}
\end{aligned}
\tag{70}
$$

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