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Measuring Oligopsony Power of UK Salmon Retailers

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Abstract *A significant increase of concentration in the UK salmon retail subsector has heightened concerns about retail firms' ability to exercise market power in the purchase of supplies (oligopsony power). To assess the extent to which retail firms have exercised oligopsony power, we develop a dynamic error correction translog profit function to model the behaviour of retailers in the input market for smoke, fillet and whole salmon. Initial estimates indicated violations of monotonicity and convexity conditions as implied by economic theory. In order to ameliorate the problem, a Bayesian technique was used to impose inequality restrictions to correct the anomaly. The final estimated indices of market power in the models were low and statistically significant but sufficiently closer to the perfect competition benchmark to indicate that retailers as a whole behaved competitively during much of the period covered by this study.*

Keywords: Salmon, market power, error correction model, translog profit function

JEL Classification: JEL-I, JEL-J

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Introduction

One of the most visible changes in the UK seafood marketing chain is that the supermarket rather than the fishmonger has become the outlet of choice for most salmon consumers. The dominance of supermarket in the retail chain for food products, including seafood, has been exacerbated by mergers, acquisitions, consolidation (Clarke *et al.,* 2002) and the declining number of fishmongers (Murray and Fofana, 2002). The consequence for seafood retailing in the UK today is a high level of concentration along the marketing chain. Such parallel increase in concentration has raised significant concerns that large retailers may be able to exercise market power over their suppliers and thereby earn supernormal profits (Dobson *et al.* 2001). This market power that retailers or buyers in general, possess vis-à-vis their suppliers has been coined as "buyer power" in the literature.

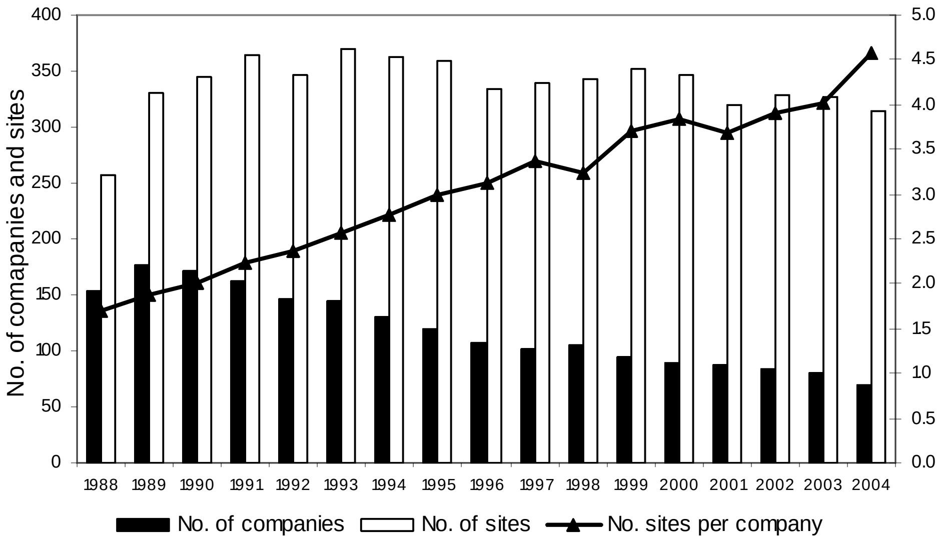
The investigation by the UK Competition Commission's (CC) (2000) of suppliers' relations with retailers indicated that lower wholesale prices in certain product categories had not been passed on to consumers. This was cited as evidence of the adverse impact on consumers of the large retailers' buying power. This is consistent with the predictions of economic theory which holds that retailers with buying power earn rent by restricting demand for goods at the upstream stage and paying suppliers a price less than that in a perfectly competitive market (e.g. Dobson *et al.* 2001). Under these circumstances suppliers find themselves worse-off since they receive a price which falls below the perfectly competitive level. It is also consistent with the CC's argument that as gate keepers, retailers with buying power exercise the wherewithal to boycott some suppliers by switching to new suppliers at short notice to take advantage of a cheaper deal. The main conclusion of the CC was that the large retail chains exercised sufficient buying power. In support of this conclusion, the CC identified 30 business practices, which, if carried out, adversely affected the competitiveness of some of their suppliers and distorted competition in the supplier market. In March 2006, the Office of Fair Trading (OFT) again signalled its plan to refer the market for the supply of groceries by retailers to the CC for more detailed investigation. The main reason for the latest OFT's action was due to further consolidation in the retail market since 2000. OFT published its review of the market for consultation and took the decision in April 2006 to refer the supply of groceries by retailers in the UK to the CC for further investigation. The OFT has not been alone in raising alarm regarding the increase in the level of concentration among food retailers. Academics and the popular press have also raised their voices regarding the growing public concern with the spiralling power of the large retail chains (e.g. Blythman 2004, Dobson 2004, Lawrence 2004). Consumer groups and trade magazines in the salmon industry, in particular, have made strong claims that supermarket chains use their buying power to obtain substantial discounts from suppliers which they never pass on to consumers (e.g. *Fish Farming Today,* No. 180 November, 2003).

There are few empirical studies of retailers' behaviour in salmon industry in the UK. Researchers who have conducted studies on market power have tended to concentrate on the oligopoly. In applied industrial economic research, the estimation of market power or price conjectures depends crucially on demand and cost functions which are sufficiently flexible, allows the imposition of theoretical restrictions, and allows for the derivation of the appropriate functional form. Previous researches on market power for salmon have relied on restrictive single models (e.g. Steen *et al.* 1997, Jaffry *et al.* 2003) to derive market power measure.

In this paper, we develop, in the tradition of the empirical industrial organisation literature, an econometric model of firm conduct with the view to measuring, explicitly, the degree of competitiveness of retailers' dealings with their suppliers in the UK salmon market. While our model complements those based on the study of single products (e.g. Steen *et al.* 1997, Jaffry *et al*. 2003), it makes a departure in that it uses a translog profit function which allows for the study of several markets more efficiently. It also allowed the imposition of regularity conditions as implied in economic theory using a Bayesian technique as enunciated by Geweke (1986) and Poirier (1995). An important aspect of Bayesian approach which we have exploited in this paper is the ease with which it is possible to impose inequality constraints on the model when regularity conditions implied in economic theory are violated. Terrell (1996) Chalfant *et al.* (1991) and Geweke (1988) had implemented a similar approach.

Concentration in the UK salmon industry

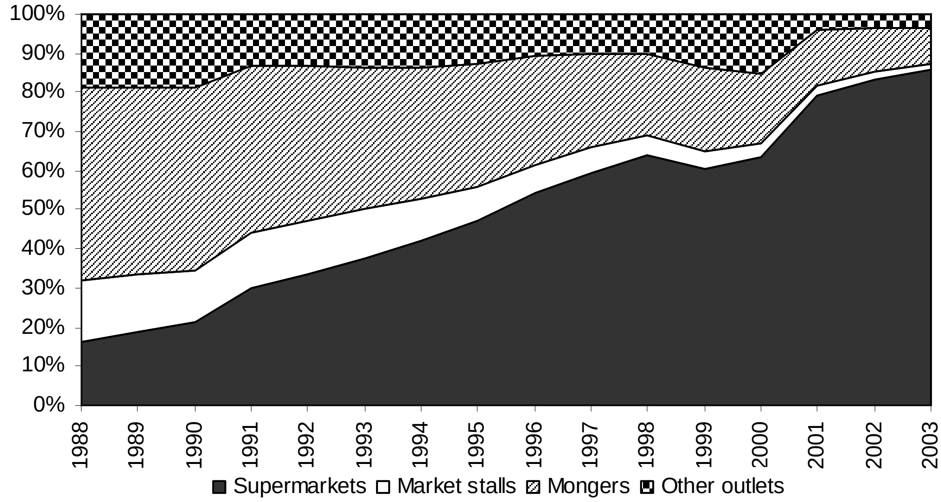
The industry has undergone a process of consolidation over the last 20 years, since 1988 the number of active companies has decreased by 44%, and in 1999 15 companies (of 95), accounted for 70% of Scottish production (SERAD 2000), (see Figure 1). In 1992, only 3% of production came from sites producing more than 1000 tonnes, but had risen to 59% in 1999. The number of firms actively producing salmon decreased to 69 firms in 2004 in comparison to 132 in 1993; a decrease of over 45%. The trend showed continued concentration of salmon production in the hands of decreasing number of firms. Similar changes are occurring at the global level where the top 5 producers have a theoretical capacity of 800,000 tonnes of salmon and trout (Intrafish 2002) which is the same amount as was produced in 1999. As consolidation occurs, and the average firm gets bigger, their role in the supply chain changes. Larger producers can take on more of the initial processing of the fish and integrate vertically. The result is a closer relationship between production and retail stages of the chain.



Source: Source: Annual Production Surveys 2004, Fisheries Research Services

Figure 1: Size and structure of the UK salmon farming industry

The most important trends for the fish retailing subsector include the ‘one-stop shop’ culture associated with increasing supermarket dominance and the increasing demand for easy to prepare meals. Large supermarket chains have therefore been much more important in fish retail. The importance of supermarkets in fish sales is manifested by the concentration ratios for UK food retailing. According to the Office for National Statistics (ONS), in 1988 the largest 5 supermarket chains in the UK accounted for only 32% of total fresh fish retail; by 1995 this share had increased to 61%. Similarly, the top 10 only accounted for 36% of the total turnover for fresh fish in 1988, but by 1998 this had increased to 71%. The market share of large supermarkets in the total retail sales has increased at the expense of the smaller retailers, mainly fishmongers. For example, the market share of fresh fish sold through large supermarket chains has increased from 16% of the market in 1988 to 86% in 2003. Over the same period, the market share of fishmongers and market stalls has declined to less than 17% and 13% of their respective numbers in 1988. The overall picture of the UK retail market for fish is depicted in Figure 2.



Source: Sea Fisheries Industry Authority

Figure 2: Household Purchase of Fresh Fish by Outlets in the UK, 1988 – 2003

As supermarkets grew, they have exerted considerable influence over the processing and wholesale sectors, requiring them to meet strict health and safety regulations, packaging and processing requirements. Only larger processors or wholesalers have been able to install the infrastructure necessary to meet these requirements. As a result processors, wholesalers and other marketing channel intermediaries have been pressured into mergers and consolidation to meet criteria set by supermarkets (Asche *et al.* 2003).

Theoretical framework

Assume that there are n (not necessarily symmetric) processing firms in the industry (indexed $i = 1, 2 \ldots N$) that produces a homogeneous product, salmon using M inputs. Also assume that firms use a quasi-fixed proportions technology in which there is a fixed proportional relationship between the material input (whole salmon) and the output (say salmon fillets), but that uses other nonmaterial inputs in variable proportions.

Theoretically the behaviour of a firm is determined by its production technology and by the economic environment in which it operates, both of which act as constraints on the firm's decision making process. Assume a profit maximisation for retailing is producing a retail good x using a homogenous technology $g(\cdot)$; the production function for the industry may be expressed as:

$$x_j = g(q_j, v_j) \tag{1}$$

where x_j is the output produced (fresh fillet, whole and smoked salmon); q_j is the input from salmon wholesalers; and v_j represents non-salmon inputs such as labour and capital. The function $g(\cdot)$ is assumed to be a twice continuously differentiable production function. In other word equation (1) represents the underlying production function relationship for output x_j.

Furthermore, assume that the j^{th} retail firm exercises some market power in purchasing the salmon products from suppliers but acts as a price taker in all other input markets. Let the inverse market supply for salmon input be given by

$$c_j = wq_j + rv_j \tag{2}$$

where q_j and v_j are the salmon product and non-salmon input used by the j^{th} firm respectively and *w* and *r* are the respective prices. The problem of decision making of the j^{th} salmon retailing firm is to choose inputs, q_j at prices so as to maximise profit $\prod_j$ subject to $x_j = g(q_j, v_j)$:

$$\prod_j = px_j - wq_j - rv_j \tag{3}$$

where x_j is the quantity of output produced by the j^{th} firm, q_j is the quantity of input used by the j^{th} firm, v_j *is a* vector of non-salmon inputs used by the j^{th} firm, $g(q_j, v_j)$ is the underlying production function relationship for output x_j, while *p* and *w* are the prices of the output, salmon input respectively and *r* is a vector of and non-salmon inputs such as labour and capital. Equation (3) is an expression of the firm's maximum level of profit (i.e., revenue minus total cost) that satisfies the properties of being positive (monotonicity), non-decreasing in *p*, non-increasing in *w*, and convex and continuous in *p* and *w*. Non-competitive behaviour is characterised by firms possessing some control in determining their input and/or output prices. The optimality condition corresponding to maximisation problem is given by:

$$p\frac{\partial x_j}{\partial q_j} = w + \left[q_j \left(\frac{\partial w(q)}{\partial q} \right) \left(\frac{\partial q\, q_j}{\partial q_j} \right) \right] \tag{4}$$

The mathematical expression on the left-hand side of equation (4) is the marginal value product (MVP) for commodity input; while the term on the right-hand side of equation (4) is the salmon retail firm's effective marginal cost (EMC). Using elasticity measures, equation (4) can now be written as

$$p\frac{\partial x_j}{\partial q_j} = w^* = w\left(1 + \frac{\theta_j}{\eta}\right) \tag{5}$$

where θ_j is the j^{th} salmon retailing firm's conjectural elasticity in the salmon wholesale commodity market, η is the price elasticity of supply of wholesale salmon. θ_j shows the i^{th} firm's perception of the percentage change in the purchases by all firms in the industry in reaction to a 1% change in own purchases. Therefore θ_j with interval [0, 1] can be interpreted as an index of market power of salmon products in the retail market. This parameter is comparable to Appelbaum's (1982) conjectural elasticity term for the output market. Chen and Lent (1992) refer to the right hand side of equation (5) as conjectural marginal input costs (CMIC) and suggest that this is useful for detecting the degree of monopsony/oligopsony power.

Azzam and Pagoulatos (1990) also suggest that the ratio θ_j/η be construed as an industry-wide index of oligopsony power in the commodity market. The index represents the degree to which retail firm can set input price below the marginal product i.e., price mark-down. With observations for the firm commodity price, w; The CMIC can be estimated with knowledge of market elasticity, η. In equation (5) if the index equal zero, a perfectly competitive market exists for the affected commodity. On the other hand if the index is not equal to zero, the commodity market is not perfectly competitive. With a little bit of mathematical manipulations and with the rearrangement of equation (5), Hyde and Perloff (1994) write the markdown, μ_q, as:

$$\mu_q = \frac{p}{w}\frac{\partial x_j}{\partial q_j} = \left(1 + \frac{\theta_j}{\eta}\right) \tag{6}$$

where μ_q is the markdown. If $\mu_q = 1$, the industry-wide index equals zero and the value of marginal product of the commodity input equals the farm commodity price. If on the hand $\mu_q \neq 1$, the index is not zero. Following Hyde and Perloff (1994), the expression for the oligopsonist price markdown factor from equation (6) can be expressed alternatively as follows $\mu_q = p/w \cdot \partial x_j / \partial q_j$ and multiplying the right hand side by $x/x \cdot q/q$ and rearranging, the following expression can be obtained:

$$\mu_q = \left(\frac{px}{wq}\right)\left(\frac{\partial x}{\partial q} \cdot \frac{q}{x}\right) \tag{7}$$

In elasticity format equation (7) can be written as $\mu_q = \xi_q / \varpi_q$; where $\xi_q = \partial x/\partial q \cdot q/x$ which is the firm's elasticity of output with respect to the commodity input and $\varpi_q = wq/px$ is the cost of the commodity input relative to value of supply.

Following Appelbaum (1979) we incorporate non-competitive behaviour, CMIC $(= w\mu_q)$ into the profit function in to equation (3), then the profit function becomes:

$$\Pi_j = \Pi_j\left[p, w, \mu_q, r\right] \tag{8}$$

Notice that output price (p) and factor prices (w, r) and market power identification variable (μ_q) are the parameters entering into profit-function. Basically the profit function in (8) maps particular factor prices to the maximum profit levels achievable at those output prices and factor prices. Taking partial derivatives with reference to choice variable (p) and (w), the first order condition for profit maximisation from equation (8) can now be written as follows:

$$x_j = \frac{\partial \Pi_j[p, w, \mu_q, r]}{\partial p} \tag{9}$$

$$q_j = \frac{\partial \Pi_j[p, w, \mu_q, r]}{\partial w} \tag{10}$$

where x_j is output supply function for salmon retailer *j*; q_j is salmon input demand. An assumption in the above formulation is that salmon retail firms in the industry are price takers in the output and input markets. Equations (9) and (10) represent salmon retailers' output supply, and salmon input demand function respectively. The output supply and factor demand functions (9) and (10) are homogenous of degree zero in *p* and *w*, i.e., only relative price changes affect supply or demand. The second-order conditions of (3) are similar to (8) and are useful for validating (9) to (10). Specification of a functional form for equations (9) and (10) allows the derivation of estimable supply and demand functions to test for the significance of μ_q the price mark-down and for non-competitive behaviour or oligopsony power in the market for salmon products.

The model specified so far is a firm level model. As is often the case in empirical work, firm level data are difficult to obtain due to confidentiality problems. Azzam and Pagoulatos (1990) highlighted that due to the lack of data on individual firm level, some assumptions must be made to enable the aggregation of firms in order to perform the analysis using industry level data. One possible assumption is to assume that in equilibrium, the market power parameter or the conjectural elasticity is invariant across firms i.e. $\theta_1 = \theta_2 = ...\theta_n = \theta$, so that all firms face identical marginal prices. The implication of this is the linear aggregation of the output and profits of firms in the industry (i.e. $x = \sum x_j$, $\Pi = \sum \Pi_j \left[p, w, \mu_q, r \right]$). It is worth noting that the first and second order conditions that apply to firm level formulation also apply to the industry model.

Empirical specification

Empirical econometric models usually encounter the usual problems of the choice of functional form of the theoretical model to apply. The choice of functional form for supply and demand functions or production technology, quasi-fixity of some inputs are among the problems to contend with. The problem is extenuated partially by using flexible function forms (Sexton and Lavoie, 2001). Consequently, in some empirical studies, the production technology is often represented by flexible functional forms (translog or generalized Leontief), but supply and demand are usually represented by simple linear or double log functions. Moreover, Perloff and Shen (2001) demonstrated that linear models produced completely unreliable estimates on account of severe multicollinearity problems.

Taking this into account we used the translog profit functional form (Christensen *et al.* 1975) and utilised the duality concept. According to duality theory, a production technology may be represented by a profit function which satisfies the following regularity properties: linear homogeneity, monotonicity, twice continuous differentiability and convexity (Diewert, 1974).

Assuming a translog profit function, equation (3) can be specified as follows:

$$\begin{aligned}\ln \Pi = {} & \beta_0 + \beta_x \ln p + \beta_q \ln w + \beta_q \ln \mu_q + \beta_v \ln r + \tfrac{1}{2}\beta_{xx}(\ln p)^2 + \beta_{xq} \ln p \ln w \\ & + \beta_{xq*} \ln p \ln \mu_q + \beta_{xv} \ln p \ln r + \tfrac{1}{2}\beta_{qq}(\ln w)^2 + \beta_{qq*} \ln w \ln \mu_q \\ & + \beta_{qv} \ln w \ln r + \tfrac{1}{2}\beta_{q*q*}(\ln \mu_q)^2 + \beta_{q*v} \ln \mu_q \ln r + \tfrac{1}{2}\beta_{vv}(\ln r)^2 \end{aligned} \qquad (11)$$

Where the subscript *x* represents the output of salmon, *q* represents the salmon wholesale inputs of fresh fillet, smoked and whole salmon and *v* represents the non-salmon inputs. For empirical implementation, salmon products are assumed to be produced from aquaculture produced salmon. Using Hotelling's lemma and substituting for μ_q partial differentiation of equation 3 with respect to salmon retailers short-run output supply, s_x, input demand, s_q, are obtained from equation (3) as:

$$\frac{\partial \ln \Pi}{\partial \ln p} = s_x = \beta_x + \beta_{xx} \ln p + \beta_{xq} \ln w + \beta_{xq*} \ln\left(\frac{\xi_q}{\varpi_q}\right) + \beta_{xv} \ln r \qquad (12)$$

$$\frac{\partial \ln \Pi}{\partial \ln p} = s_q = -\left[\beta_q + \beta_{xq} \ln p + \beta_{qq} \ln w + \beta_{xq*} \ln\left(\frac{\xi_q}{\varpi_q}\right) + \beta_{qv} \ln r\right] \qquad (13)$$

where $s_x = \dfrac{px}{\Pi}$ is the value of output to total profit

$s_q = \dfrac{px}{\Pi}$ is the value of input to total profit

Theoretical properties of equations (12) and (13) follow directly from the properties of the profit function and require that the output supply and input demand functions exhibit adding-up, homogeneity of degree zero and symmetry relationships, respectively, expressed as:

$$s_x + s_q = 1 \qquad \text{Adding up}$$

$$\beta_{xx} + \beta_{xq} + \sum_l \beta_{xv_l} = -\beta_{qx} - \beta_{qq} - \sum_l \beta_{qvl} = 0 \qquad \text{Homogeneity}$$

$$\beta_{xq} = -\beta_{qx} \qquad \text{Symmetry}$$

While the above restrictions can be imposed on the parameters during estimation on the profit function, Fulginiti and Perrin (1993) argued that monotonicity and convexity are not general properties of the translog function and they can be imposed with linear restrictions on parameters in translog models. Instead, the consistency of the estimated share equations with monotonicity and convexity properties must be evaluated after estimation. To satisfy the monotonicity condition, the shares fitted from the estimated parameters must be positive. The implications are that salmon retailers do not accept negative profits if all inputs are perfectly variable and that input costs are not less than zero. To be convex in prices, the Hessian implied by the estimated price parameters must be positive semi-definite (Chambers, 1988; Fulginiti and Perrin 1993). The implication is that for outputs, all own-price effects are positive and for inputs, all own-price effects are negative.

In addition, oligopsony behaviour of salmon retailer in the purchase of inputs is tested through estimation of the price "mark-down" (i.e. $\mu_q = \xi_q / \varpi_q$). Recall that ξ_q is now the retail industry's elasticity of salmon outputs with respect to the industry's inputs and ϖ_q is the cost of the salmon retail industry input relative to the value of supply. While ϖ_q can be derived from observed data as the input cost share of the value of the industry supply, ξ_q is unknown. However having assumed that the profit function satisfies the aggregation property, the production technology implied is quasi-homothetic and therefore constant return to scale (Chambers, 1988). That is production functions have expansion path that are straight lines that do not necessarily initiate from the origin. This assumption implies that $\xi_q = 1$. However, following Unterschultz *et al.* (2000) ξ_q is set at 0.5 to allow the evaluation of changes in the price markdown. Assuming ξ_q is constant over the sample period then

$$\mu_q = \left(\frac{1}{2}\right) \cdot \left(\frac{px}{wq}\right) = \left(\frac{1}{2}\right) \cdot \frac{s_x}{s_q} \qquad (14)$$

Any changes in the price "mark-down" μ_q will be ascribed to the ratio of the optimal shares of the value of output and the value of input. It is evident from the above expression, $\partial s_q / \partial \mu_q < 0$ and $\partial s_x / \partial \mu_q > 0$. This implies that a higher price "markdown" results in a lower share of input and a higher share of the value of output. Empirically, a statistically significant and positive estimate of the coefficient on μ_q in the output equation and a statistically significant and negative estimate of the coefficient on μ_q in the input equation suggest the absence of oligopsony power. These two conditions are central to detecting market power of salmon retailers.

The dependent variables in equations (12) and (13) are shares that do not allow easy interpretation of the effects of prices on quantities supplied. In this case retailers' responsiveness to price changes may be appropriately measured by elasticities. The elasticity measures of interest are own-price elasticities of supply and demand as well as the elasticity of demand for inputs with respect to own-price "mark-down". The Marshallian output supply and input demand elasticities can be derived from the profit share equations as $\theta_{xx} = -1 + S_x + (\beta_{xx} / S_x)$, $\phi_{xq} = S_q + (\beta_{xq} / S_x)$ for all $q \neq x$. These price elasticities are calculated at the sample means of the data. Convexity of the profit function implies that the own-price elasticities are negative for inputs.

Data and dynamic ECM specification

Some of the data available for estimation were in monthly frequencies while others were in quarterly frequencies. For consistency we follow Genesove and Mullin (1998) in aggregating up to quarterly level. Genesove and Mullin argued that this was to ensure that the estimated elasticity represents the long run elasticity as opposed to short run. In addition, the long run is considered because under imperfect competition, retailers are more likely to establish a price in the long-run rather than short-run profits in mind and to maintain that price for a considerable period of time (Jumah 2004). Therefore the data available for estimation are defined as the average quarterly 1992-2004 time series for smoked$(p_{sx_{it}})$, fillet$(p_{wx_{it}})$ and whole $(p_{sx_{it}})$salmon for retail and smoked$(p_{sq_{it}})$, fillet$(p_{wq_{it}})$ and whole $(p_{sq_{it}})$salmon wholesale prices, wage(w_{xt}, w_{qt}) in the food wholesaling sector, private sector investment indices(r_{kvx}, r_{kvq}) for food and alcoholic beverages and the generated identification price mark-down variable, (μ_q). The data on retail prices were obtained from Sea Fish Industry Authority (SFIA), while wholesale price were obtained from Scottish Quality (SQS). Wage index of food wholesalers and the index of private sector investment in food and alcoholic beverages were obtained from the Office for National Statistics.

We examined the order of integration of all the variables by applying the unit root tests. We applied the ADF (Dickey and Fuller, 1979). The ADF tests the null of no unit root in the data against the alternative of a unit root. Table 1 reports the outcome of the for the ADF tests. The tests results indicate that all variables are non-stationary in level but stationary in first differences. Overall, the conclusion drawn was that all the level variables are integrated of order one, I(1); a necessary condition for cointegration.

Table 1 Stationarity and cointegration tests for variables in the Oligopsony model, 1992-2003

Variable	Unit root test				Cointegration test	
	Level		First difference			
	Constant included	Constant + trend Included	Constant Included	Constant + trend included	ξ_{Max}	ξ_{Trace}
s_{1x}	-2.65	-2.78	-10.61*	-10.46*	64.59*	233.8*
s_{2x}	-2.39	-2.40	-4.61*	-4.47*	66.74*	236.9*
s_{3x}	-2.33	-2.27	10.47*	-7.82*	57.74**	221.1*
s_{1q}	-0.54	-1.93	-10.88*	-9.52*	60.26**	229.0*
s_{2q}	-1.03	-1.23	-9.57*	-9.55*	44.69	202.9**
s_{3q}	-2.78	-1.59	-2.52	-4.39*	58.39**	229.0*
β_{1xq}	-1.60	-1.62	-3.15**	-3.38		
β_{2xq}	-2.12	-1.71	-3.08**	-3.45		
β_{3xq}	-1.78	-1.43	-6.74*	-6.05*		
β_{1qx}	-1.98	-2.79	-9.11*	-8.47*		
β_{2qx}	-1.43	-1.93	-6.36*	-6.36*		
β_{3qx}	-2.81	-1.99	-6.34*	-6.61*		
r_{inv}	-2.16	-1.02	-9.04*	-9.75*		
r_{wages}	-1.14	-1.48	-5.11*	-5.07*		
μ_q	-2.79	-2.78	-6.72*	-6.72*		
μ_q	-1.59	-2.80	-5.45*	-5.38*		
μ_q	-1.49	-2.31	-3.39**	3.42		

*significant at 1% level, **significant at 5%.

Having identified the order of integration in the individual data series, the next step was to investigate whether or not there is a linear relationship among the variables of interest which are integrated of order one; if this is such a relationship, the variables are said to be cointegrated and an equilibrium relationship exists. Since the model contains more than two variables, the maximum likelihood method of Johansen (1988) was used to determine the distinct cointegrating relationships which exist among the variables in both the derive demand and the output supply equations. For each share equation both the trace and the maximum eigenvalue test are reported in Table 1. Both tests reject the null hypothesis of no cointegration vectors since the value of the tests for $r = 0$ is greater than the critical values at the 95% level. In addition, the tests suggest that there is at least one cointegrating vector.[1] It therefore follows that the variables are cointegrated and that an equilibrium relationship exists which can be analysed using an Error Correction Model (ECM).

The estimation of the economic models involving integrated data has been addressed using a number of methods. Ng (1995) specifically considers the issue of testing the homogeneity restriction and uses a method in which the empirical distribution of the relevant test statistics are simulated by parameterising the data generating process and using this as the basis for a Monte Carlo exercise. Attfield (1997) uses the triangular error correction model (TECM) of Phillips (1991), and in considering the theoretically implied restrictions also focuses only on the homogeneity restriction. Reziti and Ozanne (1999) estimated ECM of Greek agriculture output and input share equations derived from a translog profit function using aggregate level data. Nested within this model are both a conventional static model (STM) and three simpler dynamic models: a partial adjustment model (PAM), autoregressive error model (AEM) and finite distributed lag model (FDLM). Reziti and Ozanne adopted a sequential testing procedure to find the model which best represents the underlying data generation process. Their result indicated that the data-generating process rejects the static model and simpler dynamic models in favour of the more general error correction model.

Consequently we used the more general Anderson and Blundell (1982) technique as exemplified by Asche *et al*. (1997). We assumed the data generation process follows the Autoregressive Distributed Lag (ADL) models for reparametisation of the models used in this paper. The ADL model is an extremely flexible model for time series data, and is often seen in the following bivariate form. This can be written more compactly in vector matrix notation as follows:

$$\mathbf{y}_{\mathbf{t}} = \Pi\, \mathbf{x}_t \tag{15}$$

where y_t is a *n*-vector of budget shares; $\mathbf{x}_t$ is a *k*-vector of intercept, own price, price of other salmon products and expenditure variables; and Π is the ($n\times k$) matrix of long-run AIDS parameters. Equation (15) represents the long-run, equilibrium position. In the short-run, after changes in any of the elements of $\mathbf{x}_t$, the system may be 'out of equilibrium' for some periods as full adjustment to the equilibrium is delayed by inertia that is due to transaction costs, habits and imperfect information. However, the systems of equations as a whole may be classified as 'cointegrating' if any such disequilibrium diminishes towards zero for all products over time. This dynamic process of adjustment may be modelled by a vector-autoregressive, distributed lag (VARDL(*r*, *q*)) model:

$$\mathbf{B}(\mathbf{L})\mathbf{y}_{\mathbf{t}} = \boldsymbol{\Gamma}(\mathbf{L})\mathbf{x}_{\mathbf{t}} + \boldsymbol{\varepsilon}_t \tag{16}$$

where $\mathbf{B}^*(\mathbf{L}) = \sum_{\mathbf{i}=\mathbf{0}}^{\mathbf{p}} \mathbf{B}_{\mathbf{i}}\mathbf{L}^{\mathbf{i}}$, $\mathbf{B}_{\mathbf{0}} = \mathbf{I}$ and $\boldsymbol{\Gamma}^*(\mathbf{L}) = \sum_{\mathbf{i}=\mathbf{0}}^{\mathbf{q}} \boldsymbol{\Gamma}_{\mathbf{i}}\mathbf{L}^{\mathbf{i}}$

where ***B***(*L*) and (*L*) are matrix polynomials of orders *r* and *q*, respectively, in the lag operator ***L***, and $\boldsymbol{\varepsilon}_{\mathbf{t}}$ is an independent, identically distributed random disturbance vector. In practice, estimation is simplified if the orders of the polynomials are identical, $r = q$. Determining the value of *q* is often accomplished by estimating an initial, relatively high-order VARDL, then testing down for shorter maximum lags in an attempt to obtain a parsimonious, but data-

[1]Note that the *max* test rejected cointegration for the input demand equation for fillets but trace test indicated a cointegration relationship.

consistent model. Since researchers have often found that relatively low-order vector-autoregressive models will generally suffice in cointegration analysis of seasonally unadjusted data (Johansen, 1995), the decision was taken to carry out all estimation and inference within the context of a relatively parsimonious, first-order VARDL (q = 1).

Given that the inverse exists, the longrun structure implied by equation (16) is shown as follows.

$$\mathbf{\Pi}(\boldsymbol{\theta}) = \mathbf{B}^*(\mathbf{1})^{-1}\mathbf{\Gamma}^*(\mathbf{1}) = \left[\sum_{\mathbf{i=0}}^{\mathbf{p}} \mathbf{B_i}\right]^{-1}\left[\sum_{\mathbf{i=0}}^{\mathbf{q}} \mathbf{\Gamma_i^*}\right] \qquad (17)$$

Equation (17) can be reparameterised to give an observationally equivalent set of equation of the form:

$$\mathbf{\Delta y(t) = -B(L)\Delta w(t) + \Gamma(L)\Delta\tilde{x}(t) - B^*(1)y(t-p) + \Gamma^*(1)x(t-q) + \boldsymbol{\varepsilon}(t)} \qquad (18)$$

Where the tilde indicates that the column for the most constant term has been deleted as the dependent variable vector in both the AIDS and tranlog models adds up to unity. In the AIDS and translog models developed in the next section, it should be noted that the vector $\mathbf{y(t)}$ would correspond to the expenditure and profit shares respectively**.** The adding up restriction linked with equations (17) and (18) are:

$$i'B_i = i'm_i, \quad i = 1,....p-1, \qquad i'\Gamma_i = 0, i = 0,.......q-1, \qquad i'B^*(1) = ki'$$
$$i'\Pi = (1\ \ 0\ \ 0.......0) \qquad i'\Gamma^*(1) = (k+1 \quad 0\ \ 0.....0),$$

The covariance matrix of the equation system in (18) is singular due to the adding up conditions. As a result the system has a potential redundant variable problem since the vectors of the lagged dependent variables that sum to unity appear in each equation. Anderson and Blundell (1982) solved this problem by deleting one variable in the dependent variable vector, which also implies that the last column is subtracted from the other columns in each B_i^* matrix. The covariance matrix of the system equations in (18) is still singular as the left-hand side of the equation sums to zero. As a result one equation is dropped before estimation of the model. The invariance property to which equation to be deleted also applies in this type of systems. Letting the subscript on a matrix denote the deletion of the last row and a superscript denote a $n(n-1)$ dimensional matrix, the system to be estimated is then:

$$\mathbf{\Delta y_n(t) = -B_n^n(L)\Delta w_n(t) + \Gamma_n(L)\Delta\tilde{x}(t) - B_n^{n^*}(1)w_n(t-p) + \Gamma_n^*(1)x(t-q) + \boldsymbol{\varepsilon}(t)} \qquad (19)$$

All the parameters in (18) may be retrieved from (19) using the adding up conditions. Equation (19) provides a template for re-parametising a dynamic ECM Translog models as follows

$$\begin{aligned}\Delta s_{ix} &= \varpi_{ix} + \varpi_i \Delta s_{ixt-1} + \omega_{ixx}\ln\Delta p_{ixxt} + \omega_{ixq}\ln\Delta p_{ixqt} + \varpi_{xq}\ln\Delta w_t + \varpi_{ixq*}\ln\Delta\mu_{iqt} + \omega_{ixv}\ln\Delta r_t \\ &\quad + \varpi_{ixx}\ln\Delta p_{ixxt-1} + \omega_{ixq}\ln\Delta p_{ixqt} + \varpi_{xq}\ln\Delta w_{t-1} + \varpi_{ixq*}\ln\Delta\mu_{iq_{t-1}} + \varpi_{xv}\ln\Delta r_{t-1} + \varpi_{ixx}\ln p_{ixxt-2} \\ &\quad \omega_{ixq}\ln p_{ixqt-2} + \omega_{xq}\ln w_{t-2} + \omega_{ixq*}\ln\mu_{qit-2} + \omega_{xv}\ln r_{t-2} + \sum_{\mathrm{k=1}}^{3}\rho_{\mathrm{ik}}\mathrm{s}_{\mathrm{ik}} + \varepsilon_{\mathrm{it}} \qquad (20)\end{aligned}$$

$$\Delta s_q = \omega_i \Delta s_{t-1} - [\omega_{iq} + \varpi_{iqq} \ln \Delta p_{iqqt} + \varpi_{iqx} \ln \Delta p_{iqxt} + \omega_{iqq} \ln \Delta w_t + \varpi_{qx*} \ln \Delta \mu_q + \varpi_{iqv} \ln \Delta r_t$$
$$\varpi_{iqq} \ln \Delta p_{iqqt-1} + \varpi_{ixq} \ln \Delta p_{ixqt-1} + \varpi_{iqq} \ln \Delta w_{it-1} + \omega_{iqx} \ln \Delta \mu_{iqt-1} + \omega_{qv} \ln \Delta r_{t-1} + \omega_{ixq} \ln p_{ixqt-2}$$
$$\varpi_{iqq} \ln p_{iqqt-2} + \omega_{qq} \ln \Delta w_{it-2} + \omega_{iqx} \ln \Delta \mu_{qt-2} + \varpi_{qv} \ln \Delta r_{t-2}] + \sum_{k=1}^{3} \rho_{ik} s_{ik} + \varepsilon_{it} \qquad (21)$$

where ε_{it}, s_{ik} and ϖ are the error terms, quarterly dummy variables and parameter to be estimated in the demand and supply equation respectively. The inclusion of seasonal dummies is based on previous salmon demand and supply studies, which indicate that seasonality is important in the industry (Steen *et al*. 1999 Asche *et al*. 2004). All other variables in equations (20) and (21) are as defined previously. The specification of the equation (21) means that retailers' demand for input does not only depend on its own price but also on the price of the product at retail level. For the supply equation (21) the supply of salmon product at retail level does not only depend on its own price, but also on the price of the product at wholesale level.

Empirical results

The determination of oligopsony power of salmon retailers involved the simultaneous estimation of the ECM translog input derived demand and output supply models, that is equations (20) and (21) respectively. Input prices, output prices and all nominal variables were deflated by the consumer price index. This implicitly imposes the homogeneity property in the supply and demand functions. Symmetry conditions are imposed during the estimation procedure. The systems of two input-derived demand and supply equations for smoked and fillet salmon products were estimated simultaneously using Seemingly Unrelated Regression (SUR) procedure (Zellner, 1962). The third equation for whole salmon from each system was deleted because of singularity of the variance matrix for all four equations, and parameters of that equation were obtained through the homogeneity and symmetry restrictions. By iterating over both the parameters and the error variance-covariance matrix, the estimates obtained are invariant to the equation chosen for deletion (Barten, 1969). Seasonality was taken into account by using quarterly seasonal dummies, S_1, S_2, and S_3. Lagging the dependent share equations by one period was sufficient to get rid of any autocorrelation problems

Since the parameters are first and second order logarithmic derivatives of the profit function evaluated at the approximation point, economic theory provides no prior expectations about their signs (Weaver, 1983). The validation of the models must rely on the overall fit of the system; on significance of the coefficients; and on whether or not the estimated profit function satisfies the monotonicity, convexity, and symmetry conditions. While the properties of homogeneity and symmetry were imposed, monotonicity was tested using the estimated parameters to predict shares at each data point. The monotonicity property is satisfied when predicted shares are positive at each data point. For convexity in prices, all own-price elasticities should have the expected signs; that is, positive for output supply and negative for input demand (Chambers, 1988).

The preliminary estimates of the parameter from the systems of equations for output supply and input derived demand are reported in the Appendix in Tables A1 and A2 respectively. The Appendix also provides a brief analysis of the results of the unrestricted model. In all, the diagnostics of the model in terms of R^2, variance of the models for the value added products are within acceptable ranges. However, few parameter estimates from the unrestricted models are statistically significant at the 1% and 5% levels. Notably, the models violated the monotonicity, concavity and convexity conditions implied by economic theory. In addition the elasticities estimated from these models were also of the wrong signs. To be consistent with the behavioural postulates of economic theory, the estimated models must satisfy all or at least most of the properties of a well-behaved profit function which result from profit maximisation hypotheses. Therefore this problem must be fixed to improve the predictive power of the models. This paper uses Bayesian approach to impose restrictions.

Imposing restrictions using the Bayesian approach

The objective is to obtain consistent index of retailers' oligopsony power for the three value added products of salmon. To be able to do this the estimated model should exhibit comparative-static regularities following from economic theory. A widely applied solution to the problem is the imposition of regularity conditions globally[2], i.e. impose restrictions on all values of the regressor space (see Diewert and Wales 1987). For most flexible functional forms, however, such restrictions come at the cost of limiting the flexibility with regard to representing other economic relationships. For example, under the imposition of global concavity, the cost functions do not allow for complementary relationships among inputs. Kleit and Terrell (2001) argued that global restrictions also causes the translog models to overestimate own-price elasticities and also biases price elasticities.

Barnett (2002) and Barnett and Pausaupathy (2003) argued that the 'monotonicity' regularity condition has been mostly disregarded in estimation, leading to questionable interpretability of the resultant empirical economic models. A fundamental difficulty, however, is that imposing both curvature and monotonicity can dilute the property of second order flexibility. For the special case of finite linear-in-the-parameters functional forms, which is the most common in empirical applications, Lau (1978) proved that flexibility is incompatible with global regularity if both concavity and monotonicity are imposed. Thus, maintaining higher order flexibility requires giving up *global regularity* in favour of imposing restrictions locally.

The *local approach* maintains the flexibility property of a functional form if the regularity conditions are imposed at one selected point of the regressor space (Ryan and Wales 1998). The risk with this approach is that regularity may be violated in a neighbourhood of this selected point. Because of this dilemma, the literature on flexible functional forms is characterised by a continual investigation for new functional forms that produce relatively large regular regions. Nonetheless, for a given data set, searching for alternate forms and applying and testing the regularity conditions on a case by case basis becomes an arduous task, that can also be rife with statistical testing/verification problems. In order to maintain flexibility involves the imposition of regularity conditions locally, Gallant and Golub (1984) proposed an inequality constrained optimisation program to impose regularity conditions *locally* at each observed regressor value. This methodology was further expounded by Griffith (1988) and applied by numerous authors including Terrell (1996), Chalfant, Gray and White (1991). Compared with the global approach, this method generally increases the fit of the model to the data. This study follows the local approach of imposing restrictions using Bayesian approach to achieve monotonicity and concavity. These constraints were imposed only over the region of the ECM derived input demand and output supply equation where inference was drawn.

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[2] It is possible to impose global curvature restrictions, for example, using eigenvalue decomposition methods and methods involving Cholesky factorisation (e.g. see Coelli, and Perelman , 1996).

As already discussed homogeneity is implied by working with real prices while symmetry conditions are imposed. These restrictions from theory represent prior information that can be imposed on flexible forms through equality restrictions on the parameters. Chalfant *et al.* (1991) highlighted that such restrictions reduce the dimensionality of the parameter space when systems of equations based on these forms are estimated. For example homogeneity and symmetry provide considerable gains in degrees of freedom. Prior information taking the form of an inequality restriction is less informative than such equality restrictions, in the sense that this information serves to truncate the parameter space, rather than reduce the number of free parameters. Conventional approaches to estimation do not permit the formal inclusion of such information (Judge *et al.* 1988). Chalfant *et al.* (1991) argued that the problem of prior beliefs that take the form of inequality constraints is easily handled in the context of Bayesian inference.[3]

To describe the method, a data generating process was first assumed. It was also assumed that input and output prices may be treated as exogenous, so that the parameters of the system of $n-1$ equations for profit shares could be estimated using seemingly unrelated regressions (SUR). As is well known, the equation for the *nth* profit share cannot be included without implying a singular contemporaneous covariance matrix for the error terms in the *n* share equations (Barten 1969). But deleting the *nth* share and using restrictions on the parameters allows the complete set of parameter estimates to be obtained. Use of iterated SUR was shown by Barten to lead to maximum-likelihood estimates that are invariant to the equation chosen for deletion. It is assumed that each time period's *n-1* vector of errors, and therefore the vector of profit shares, follows the multivariate normal distribution.

Using the Bayesian procedure as outlined by Griffiths (1988), Chalfant *et al.* (1991) suggest that the probability that the basic idea is to compute Bayes estimates as the mean of truncated multivariate t-posterior. For instance let us assume the parameter estimates $\hat{\beta}$ with a variance-covariance estimate $V(\hat{\beta})$ distribution. Empirical implementation of the Bayesian approach involves the use of Monte Carlo numerical integration that is implemented by generating replication from multivariate t- distribution. At each replication i the vector w_i is drawn from a $N(0, V(\hat{\beta}))$ and draws another vector z_i from a χ^2 distribution with say, v degrees of freedom. This procedure was followed to obtain a sample size of 500,000 replications (including antithetic replications) from the multivariate t-distribution with 6 restrictions which is also equivalent to the degrees of freedom.

Results and theoretical validation of the constrained models

In all, four equations were estimated, that is two equations each from the derived demand and supply functions. The parameter estimates, their standard error are given in Tables 2 and 3 for the constrained output supply equation and input demand equation respectively.

Table 2: Constrained results of the output supply

[3] See Griffiths (1988), Chalfant, Gray and White (1991) for an excellent introduction to inequality restrictions in the Bayesian framework.

	Smoke		Fillet	
Variable	Parameter	Numerical	Parameter	Numerical
Δs_{1xt-1}	-0.0952*	0.0004	-0.0298*	0.0006
$\ln \Delta p_{1xxt}$	0.0289*	0.0004	-0.0344*	0.0005
$\ln \Delta p_{1xqt}$	0.0057*	0.0003	-0.0066*	0.0003
$\ln \Delta r_{invt}$	-0.1713*	0.0008	0.1679*	0.0010
$\ln \Delta r_{wagest}$	-0.1780*	0.0011	0.0957*	0.0013
$\ln \Delta \mu_{iqt}$	0.0796*	0.0002	0.0085*	0.0001
$\ln \Delta p_{1xxt-1}$	0.0854*	0.0004	-0.0519*	0.0005
$\ln \Delta p_{1xqt-1}$	0.0236*	0.0003	0.0192*	0.0003
$\ln \Delta r_{invt-1}$	-0.1993*	0.0008	0.0935*	0.0010
$\ln \Delta r_{wagest-1}$	0.2014*	0.0011	-0.3446*	0.0013
$\ln \Delta \mu_{iqt-1}$	0.0356*	0.0002	-0.0055*	0.0001
$\ln p_{1xxt-2}$	0.312*	0.0001	0.338*	0.0001
$\ln p_{1xqt-2}$	-0.0111*	0.0001	-0.0141*	0.0001
$\ln r_{invt-2}$	0.0122*	0.0004	0.0168*	0.0005
$\ln r_{wagest-2}$	-0.0266*	0.0006	-0.0067*	0.0008
$\ln \mu_{iqt-2}$	0.0078*	0.0002	0.0097*	0.0001
S_2	-0.0695*	0.0003	0.0183*	0.0003
S_3	0.0181*	0.0004	-0.0347*	0.0004
S_4	0.1826*	0.0003	-0.1657*	0.0004

* significant at 1% level

Table 3: Constrained results of the input derived demand

Smoke			Fillet	
Variable	Parameter	Numerical	Parameter	Numerical
Δs_{1qt-1}	-0.0615*	0.0005	0.0160*	0.0002
$\ln \Delta p_{1qqt}$	-0.0016*	0.0004	-0.0062*	0.0002
$\ln \Delta p_{1qxt}$	-0.0131*	0.0003	-0.0126*	0.0001
$\ln \Delta r_{invt}$	-0.0486*	0.0008	0.0541*	0.0003
$\ln \Delta r_{wagest}$	-0.1442*	0.0012	-0.0102*	0.0004
$\ln \Delta \mu_{iqt}$	-0.1258*	0.0002	-0.0397*	0.0000
$\ln \Delta p_{1qqt-1}$	0.0305*	0.0004	0.0020*	0.0002
$\ln \Delta p_{1qxt-1}$	-0.0120*	0.0003	-0.0016*	0.0001
$\ln \Delta r_{invt-1}$	-0.1209*	0.0008	0.0441*	0.0003
$\ln \Delta r_{wagest-1}$	0.0973*	0.0011	-0.0639*	0.0004
$\ln \Delta \mu_{iqt-1}$	-0.0353*	0.0005	0.0143*	0.0002
$\ln p_{1qqt-2}$	0.0119*	0.0001	0.0138*	0.0001
$\ln p_{1qxt-2}$	-0.311*	0.0001	-0.241*	0.0001
$\ln r_{invt-2}$	0.0172*	0.0004	0.0157*	0.0002
$\ln r_{wagest-2}$	-0.0330*	0.0006	-0.0216*	0.0003
$\ln \mu_{iqt-2}$	-0.0028*	0.0002	-0.0003*	0.0000
S_2	-0.0514*	0.0003	0.0000	0.0001
S_3	0.0008*	0.0004	-0.0214*	0.0001
S_4	0.1163*	0.0003	-0.0270*	0.0001

* significant at 1% level

Not surprisingly, given the estimation technique employed here, nearly all of the parameters estimates appear to be significantly different from zero.

The intuition of imposing constraints on the models is better understood by checking whether the model satisfies the theoretical properties of the function from which it is derived. Homogeneity and symmetry were imposed in the estimation process but monotonicity and convexity were not. Most of the predicted shares are positive implying that the translog profit function largely satisfies the property of monotonicity. In an economic sense, this implies there are no negative profits for salmon when inputs are perfectly variable. The property of convexity in prices was ascertained by the sign of the estimated demand and supply elasticities.[4] The own price derived demand elasticities for smoked and fillets are -0.24 (0.0001) and -0.31 (0.162) respectively while the own price supply elasticities are 0.12 (0.0002) and 0.27 (0.003) for smoke and fillets respectively.[5] A convex profit function

[4]Convexity requires that all eigen values of the sub-matrix of estimated price coefficients be non-negative and that at least one should be zero for positive semi-definiteness. The price coefficients of the longrun parameters in each equation were used to estimate eigen values. The eigen value tests for both input demand and output supply largely satisfy the condition for positive semi-definiteness.

[5] Standard error in parenthesis.

implies that retailers can always keep output and cost constant but still increase profit with an increase in output price. This is the first study that estimates the demand and supply elasticities for salmon retailers in the UK so comparison cannot be made with any other study.

Although the aforementioned discussion of the empirical results is insightful, a key component of any market power study are the conduct market power parameters attached to $\ln \mu_{iqt-2}$, an equivalent of price "mark-down" which are reported in Tables 2 and 3. The estimated mark-down parameters from the supply and derived demand equations for smoke salmon are 0.0078 and -0.0028 respectively; while the markdown parameters from the supply and derived demand equation for salmon fillets are 0.0097 and -0.0003 respectively. While the estimated parameter is statistically significant, the estimated parameters are sufficiently closer to zero to conclude that retailers do not have oligopsony power over their suppliers. A possible explanation for this finding is that retailers as a whole behaved competitively during much or most of the period covered by this study. This possibility seems likely, especially when one considers that oligopsony power is very small in several studies of similarly concentrated agricultural product retailing sector. In this regard, the results are largely in agreement with those of other studies that have analysed the competitiveness of salmon markets (see Asche *et al*. 2006). However, it should be noted, that the results obtained in this paper should not be taken as evidence that the UK retail markets for salmon products are competitive. It could be the case, for instance, that salmon retail firms did engaged in anticompetitive conduct as industry concentration increased, but that the information contained in the data is not sufficiently strong to detect such conduct using the empirical methods employed. Nevertheless, the signs on the parameters and the statistical significance of the parameters appear to suggest that there was a limited ability or potential for retailers to exert some oligopsony power in the market for the smoked salmon and salmon fillet.

Summary and Conclusion

Salmon products have now become affordable to the ordinary consumer despite the highly concentrated channels by which the supplies are obtained. In order to gain an understanding of the transformation of the retail sector for salmon products, we develop economic models of firm conduct based on the empirical industrial organisation literature to determine oligopsony power of salmon retailers in the UK domestic market. Three value-added products of salmon were examined; the smoked, fillet and whole salmon.

In the determination of oligopsony power of salmon retailers, the translog profit function for each value-added product was specified as an ECM translog functional form and one output supply and one factor demand models were estimated for each of the three product forms. Initial estimation of the models violated behavioural conditions of monotonicity and convexity in prices implied in economic theory. To be consistent with the behavioural postulates of economic theory, a Bayesian technique was used to constrain the models by imposing local inequality restrictions on some parameters to improve the predictive power of the models. The constrained model estimates differ from the unconstrained estimates in several respects; the signs and magnitudes of coefficients and elasticities associated with the salmon products underwent noticeable change. The mark-down price parameters in the equation indicate that retailers do not have oligopsony power over their suppliers. Nevertheless, the signs on the parameters and the statistical significance of the parameters appear to suggest that there was a limited ability or potential for retailers to exert some oligopsony power in the market for the smoked salmon and salmon fillet. However, it is also appropriate to state the estimates in this paper should be treated with some caution due uncertainties inherent in some of the data used. For instance, the cost of labour for food manufacturing was used instead of labour in fish processing due to inaccessibility of the latter.

An important limitation of this paper and others analysing oligopsony market power in the salmon industry is the absence of product differentiation and market segmentation. By estimating a model assuming commodity homogenous products, this study is ignoring the rapid change of UK. Retailers are expanding their production operations to include the production of pre-packed and ready-to-eat salmon meals via differentiation strategies such as branding. However, the degree of product differentiation is relatively unknown and data are sparse which further exacerbates the difficulties of researching in this area.

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Appendix

Table A1: Unconstrained results of the output supply

Share Equation	Smoke		Fillets	
	Parameter	**Standard**	**Parameter**	**Standard**
ϖ_{ix} (Constant)	0.000	0.026	-0.020	0.033
Δs_{1xt-1}	-0.089**	0.039	-0.035	0.048
$\ln \Delta p_{1xxt}$	0.013	0.032	-0.050	0.045
$\ln \Delta p_{1xqt}$	0.012	0.022	-0.004	0.026
$\ln \Delta r_{invt}$	-0.187*	0.067	0.170**	0.083
$\ln \Delta r_{wagest}$	-0.129	0.099	0.103	0.117
$\ln \Delta \mu_{iqt}$	0.086*	0.015	0.009	0.011
$\ln \Delta p_{1xxt-1}$	0.081**	0.036	-0.068**	0.045
$\ln \Delta p_{1xqt-1}$	0.049**	0.026	0.030	0.030
$\ln \Delta r_{invt-1}$	-0.218*	0.067	0.097	0.083
$\ln \Delta r_{wagest-1}$	0.250*	0.096	-0.337*	0.116
$\ln \Delta \mu_{iqt-1}$	0.049*	0.018	-0.006	0.011
$\ln p_{1xxt-2}$	-0.004	0.012	-0.001	0.017
$\ln p_{1xqt-2}$	0.033 ***	0.023	-0.001	0.015
$\ln r_{invt-2}$	-0.026	0.039	0.006	0.045
$\ln r_{wagest-2}$	0.019	0.055	0.011	0.070
$\ln \mu_{iqt-2}$	0.027***	0.018	-0.006	0.009
S_2	-0.068*	0.027	0.023	0.030
S_3	0.019	0.031	-0.032	0.034
S_4	0.187*	0.027	-0.164*	0.031
R^2	0.88		0.77	
σ^2	0.0010		0.0016	

*significant at 1% level,; ** significant at 5% level; *** significant at 10% level

Table A2: **Unconstrained results of the input derived demand**

Share Equation	Smoke		Fillet	
Variable	Parameter	Standard	Parameter	Standard
ϖ_{iq} (Constant)	0.006	0.027	-0.007	0.009
Δs_{1qt-1}	-0.055	0.045	0.015	0.017
$\ln \Delta p_{1qqt}$	-0.017	0.036	-0.012	0.016
$\ln \Delta p_{1qxt}$	-0.007	0.027	-0.007	0.012
$\ln \Delta r_{invt}$	-0.063	0.069	0.054 **	0.023
$\ln \Delta r_{wagest}$	-0.094	0.102	-0.003	0.033
$\ln \Delta \mu_{iqt}$	-0.120*	0.018	-0.039*	0.004
$\ln \Delta p_{1qqt-1}$	0.024	0.039	-0.006	0.018
$\ln \Delta p_{1qxt-1}$	0.014	0.030	0.007	0.014
$\ln \Delta r_{invt-1}$	-0.140**	0.069	0.043	0.023
$\ln \Delta r_{wagest-1}$	0.147 ***	0.099	-0.057 **	0.033
$\ln \Delta \mu_{iqt-1}$	-0.016	0.043	0.013	0.017
$\ln p_{1qqt-2}$	-0.004	0.012	-0.001	0.017
$\ln p_{1qxt-2}$	0.033 ***	0.023	-0.001	0.015
$\ln r_{invt-2}$	-0.020	0.039	0.003	0.019
$\ln r_{wagest-2}$	0.012	0.056	0.001	0.031
$\ln \mu_{iqt-2}$	0.015	0.021	0.002	0.004
S_2	-0.050 **	0.029	0.001	0.009
S_3	0.002	0.034	-0.022 **	0.010
S_4	0.121*	0.030	-0.027*	0.009
R^2	0.92		0.87	
σ^2	0.001		0.0001	

* significant at 1% level,; ** significant at 5% level; *** significant at 10% level

The R^2 values for individual equation are quite good. The R^2 for the output supply equation were 0.88 and 0.77 for smoke and fillet respectively, and few parameters estimates are statistically significant at the 1% and 5% levels. For the input derived demand equation, the R^2 statistics were 0.92 and 0.87. Like the output supply model, the significant estimated parameters in the input demand model are few. The LM statistic values are measures of first-order serial correlation in the estimated models. The computed LM χ^2 statistic values obtained for the input demand for smoke salmon and salmon fillet are 4.74 and 0.95 respectively. For the output supply, the computed LM χ^2 statistic values obtained for smoke salmon and salmon fillet are 1.99 and 0.75 respectively. Comparing the tabulated critical statistics of 5.99 for 2 degrees of freedom with the computed statistics for both input demand and out demand equations suggest that serial correlation is not a problem in the models. The variance of the estimates $\left(\sigma^2\right)$, which is a measure of the difference between observed variation and predicted variation in the shares equations, is also used to validate the models. Variance estimate for smoke salmon input demand equation is 0.001 and while the variance for whole salmon input demand equation is 0.0001. In the out supply equation variances are 0.001 and 0.002 for smoke and salmon fillet respectively. Low variance estimates are indications of good predictive abilities of estimated models.