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The Global Competition for Wild Fish Resources between Livestock and Aquaculture

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Abstract

Aquaculture satisfies a growing global demand for fish but also consumes an increasing share of the world's wild fish resources. This has led to a concern that increased aquaculture production poses a threat to the sustainability of capture fisheries. We use a shrinkage estimator to estimate fishmeal demand from countries with different make-up of meat and farmed salmon production. Although we are not able to identify structural differences between these sectors, the empirical results show that fishmeal demand is price inelastic. Technological change, however, is reducing fishmeal usage in feeds, suggesting that strong demand pressure on pelagic fish resources targeted for fishmeal is a temporary phenomenon.

Keywords: *Aquaculture; demand analysis; farmed fish feed; fisheries; sustainable production.*

JEL classifications: *Q22*, *Q21*, *Q27*, *Q11*.

1. Introduction

Fish plays an important role as a provider of healthy animal proteins to the human diet. Global fish consumption has doubled since 1973 (Delgado *et al*., 2003).[2] Increased demand for fish has been driven by economic growth in developing regions, increased demand for healthy proteins and a need to feed a growing population. This contrasts with the situation of stagnating supply from capture fisheries

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[2] Despite the increase in total global demand, global per capita food fish supply only rose from 15.3 to 16.7 kg from 1995 to 2006 (FAO, 2001, 2009).

worldwide. Eighty per cent of all fish stocks are characterised as fully exploited or overexploited (FAO, 2009). The supply constraints in capture fisheries have created opportunities for aquaculture. Policy makers in many countries have encouraged growth of aquaculture to increase employment opportunities in rural areas, and also out of concern for the food fish supply and the sustainability of capture fisheries.

However, the reliance on wild-caught fish resources in aquaculture feeds represents a challenge for the expansion of several intensively farmed species.[3] Around one-third of global fish catches is reduced to fish oil and fishmeal for use in livestock and aquaculture feeds. Several studies have addressed the increasing demand for marine proteins out of concern for the sustainability of wild fish stocks and the viability of continued growth of intensive aquaculture (e.g. Naylor *et al.*, 2000; New and Wijkstrom, 2002; Delgado *et al.*, 2003; Hannesson, 2003; Asche and Tveterås, 2004; Kristofersson and Anderson, 2005; Tacon, 2005; Drakeford and Pascoe, 2008; Tacon and Metian, 2008; Mullon *et al.*, 2009). We contribute to this research by concentrating on demand for fishmeal from aquaculture and the livestock sectors; we address the degree to which increased aquaculture production may pose as a threat to the sustainability of capture fisheries.

Sustainable management of fish stocks is difficult due to property rights and technological issues and, as a result, aquaculture's and livestock's demand for fishmeal plays an important role in the sustainability of feed fisheries. Asche and Tveterås (2004) have argued that increasing aquaculture production will not pose a threat to the sustainability of capture fisheries, as long as both the livestock and aquaculture sectors consume fishmeal. They reason that the livestock sector switches to less expensive vegetable protein sources when fishmeal becomes relatively more expensive, thereby mitigating demand pressure from aquaculture. Hannesson (2003) shows that this will no longer hold true if the aquaculture sector becomes the dominant player in the fishmeal market. An expanding aquaculture sector will displace the livestock sector's consumption of fishmeal and lead to scarcity of marine proteins and, consequently, increasing fishmeal prices. The result will be increased pressure on feed fisheries. The results in both of these studies are based on an assumption that fishmeal demand from aquaculture is more inelastic than the demand from the livestock sector. One purpose of our study is to provide empirical estimates of the derived demand for fishmeal to test the degree to which this assumption is in accordance with reality. Such estimates will contribute to explaining the effect of increased aquaculture production on capture fisheries.

Estimating derived demand presents several challenges, however. First, aquaculture consists of different technologies and many different species, several of which do not rely on marine inputs in their feed. Instead of attempting to present the 'representative' aquaculture species when estimating fishmeal demand, we opted for a high-value species that is farmed in an intensive production system, namely farmed salmon. Salmon aquaculture represents an export-oriented industry, which in terms of volume accounts only for a small proportion of global aquaculture production. However, because of high inclusion rates of marine inputs in salmon feed, farmed salmon consumes more fishmeal than most other form of aquaculture production.

[3] Intensive aquaculture refers to farming practices characterised by a high level of control of all the stages of the biological production process.

Of the total fishmeal consumed by aquaculture in 2003, 23% went to shrimp aquaculture and 19% went to salmon aquaculture, not counting trout species (Tacon, 2005). Consequently, high-value species like salmon are among the most important when evaluating fishmeal demand from aquaculture.

A second challenge relates to available data. As disaggregated data on fishmeal consumption are unavailable, individual estimates of fishmeal demand from the livestock and aquaculture sectors are difficult to obtain. We attempt to circumvent the lack of disaggregated data by discriminating between countries that have large salmon aquaculture sectors and countries that primarily are livestock producers. In this way, aggregate country-level data can be used to estimate sector-level demand for fishmeal. Finally, few observations represent a challenge, as is often the case in demand analysis. We used a panel of 12 countries with 30 annual observations each. If, on the one hand, we estimate demand for fishmeal using single equations, there is little flexibility because of too few degrees of freedom, whereas, on the other hand, if we use standard panel data models with only heterogeneity in intercepts, cross-country heterogeneity in demand elasticities is removed. The shrinkage estimator for panel data proposed in Maddala *et al*. (1997) is a Bayesian technique that makes a trade-off between these two extremes. This estimator enables us to exploit information from the entire panel while retaining heterogeneity among individuals (Maddala *et al*., 1997). Hence, we were able to discriminate between countries with structural differences in fishmeal demand.

In the next section we outline some important features of the fishmeal market relating to the structure of demand and supply. The data are presented in the subsequent section, followed by the empirical model specification. The shrinkage estimator is described before the presentation of the results from the estimation of the model. The final section provides summary and conclusions.

2. Background

Since the 1970s there has been a sharp growth in intensive aquaculture production. Figure 1 shows the increase in intensive aquaculture production during the last three decades alongside figures for pork and poultry production. The figures for aquaculture production are based on species like salmon, tilapia, shrimp and several others that often are farmed intensively. From 1985 to 2006 the annual average

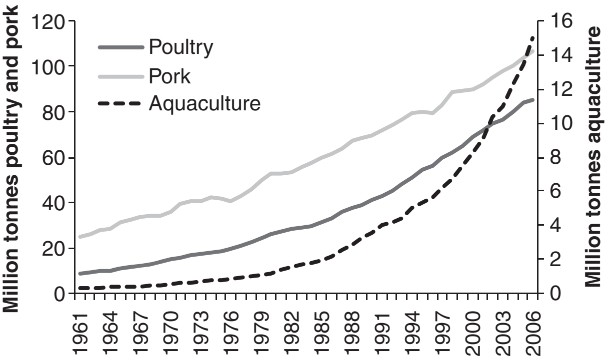

Figure 1. Global pig, poultry and intensive aquaculture production from 1961 to 2006 (***Source***: FAO databases FAOSTAT Agriculture and FISHSTAT)

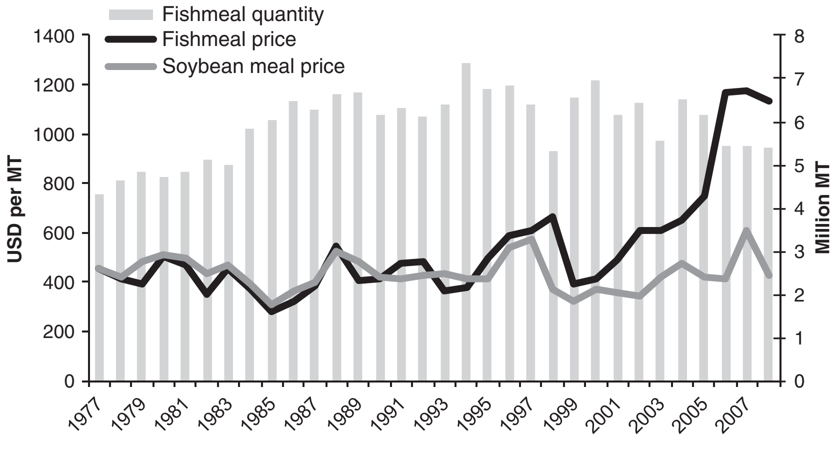

Figure 2. Global fishmeal production and prices of fish and soy proteins (***Sources***: FAO Fisheries Department, 2000 and Oil World Ista Mielke)

increases in pork and poultry production were 2.8% and 4.9%, whereas in the same 15-year period intensive aquaculture production experienced a 10.3% annual growth rate. These trends reflect the global increase in human consumption of fish and animal proteins. Further expansion in livestock and aquaculture production implies that the demand for protein feed, including fishmeal, will increase.

Global fishmeal production is concentrated among a handful of countries. Peru is the world's largest fishmeal producer and accounts for over 50% of global output together with Chile, the second largest fishmeal producer. The Nordic countries – Iceland, Norway and Denmark – constitute the second most important group of fishmeal-producing countries, with around 15% of global output.

Most pelagic stocks targeted for reduction to fishmeal have stabilised during the past 15 years. However, the industrial fisheries can vary considerably from year to year due to fluctuations in biological and climatic conditions such as those caused by the El Niño weather phenomenon.[4] Note, for example, how the 1997–1998 El Niño reduced output in 1998 (Figure 2). Because of the biological constraints, long-run supply can be viewed as stochastic around a stationary mean slightly below six million metric tonnes, as shown in Figure 2 (FAO Fisheries Department, 2000). If we compare the development of meat and aquaculture production in Figure 1 with the production of fishmeal in Figure 2, it is apparent that fishmeal inclusion in feeds must, on average, have diminished.

Figure 2 also includes annual averages of fishmeal and soybean meal prices. The soybean meal price has been normalised to the 1977 fishmeal price to clarify the covariance between the two protein meals.[5] These prices were aligned until the mid-1990s when the fishmeal price started to increase relative to soybean meal. The co-movements in prices reflect substitution between fishmeal and soybean meal

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[4] The El Niño southern oscillation refers to the occurrences of unusual warm sea-surface temperature in the southern hemisphere of the Pacific, which suppresses the upwelling of nutritious cold water, thereby drastically reduces the Anchoveta fisheries, amongst others.

[5] Soybean meal is less expensive than fishmeal and the actual average price of soybean meal in 1977 was USD 230 per tonne.

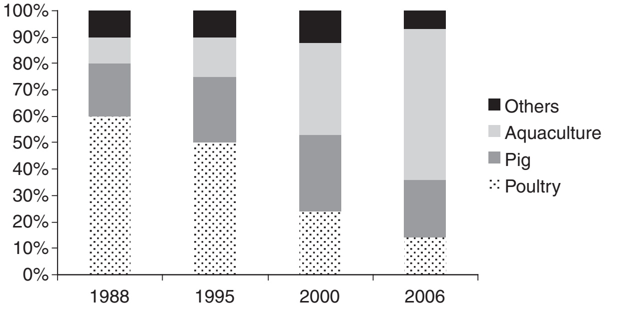

Figure 3. Share of fishmeal used in different livestock and aquaculture feeds 1988 and 2006 (***Source***: International Fishmeal and Fishoil Organization)

(Vukina and Anderson, 1993; Asche and Tveterås, 2004).[6] The surge in fishmeal prices, however, reflects a scarcity of marine proteins in the feed market and a decoupling from the vegetable proteins market.

The aquaculture sector has traditionally preferred marine proteins as they meet the nutritional requirements of farmed fish. As a result, the growth of aquaculture has resulted in a larger share of global fishmeal production targeted for fish feeds. Figure 3 shows that the poultry-, pork- and aquaculture-producing sectors consumed 60%, 20% and 10%, respectively, of the global fishmeal supply in 1988. By 2006, the poultry sector's share of fishmeal consumption had fallen to 14%, whereas the aquaculture sector's share increased six times to 57%. The pork sector had a slight increase in its share to 22%.

It is interesting to note that the pork industry's share of fishmeal consumption has been relatively stable, implying that the pork industry is less vulnerable to fishmeal price increases. In pig and poultry feeds, inclusion rates vary between 0% and 10% but are usually below 5%. By contrast, fishmeal inclusion in salmon feed can be as high as 40–45% of the feed. Consequently, changes in the fishmeal price have a much bigger impact on production costs for salmon than for pig and poultry feed. Second, fishmeal makes for a valued protein input in the feeds of simple-stomached animals due to its favourable balance of amino acids, vitamin B content and positive effect on growth, particularly in the early stages (FAO, 1983). As early-weaned pigs, for example, grow faster with marine proteins, and fishmeal accounts for a small part of the feed costs, then it may still be profitable to include marine proteins, even when fishmeal prices are at relatively high levels. This can explain some of the tendencies of market segmentation between fishmeal and soybean meal.

Finally, if we look at the development of fishmeal usage in salmon feeds it is clear that proportion of feed is reducing. This is clear from Figure 4, which shows that although salmon production steadily have been increasing, fishmeal consumption has levelled off. The figures for fishmeal usage in salmon feed have been compiled

[6] Fishmeal is also substituted with other vegetable protein sources such as rapeseed meal, sunflower seed meal, maize meal, linseed meal, etc. Soybean meal production is the largest, however, and has a dominant role in the protein meal market.

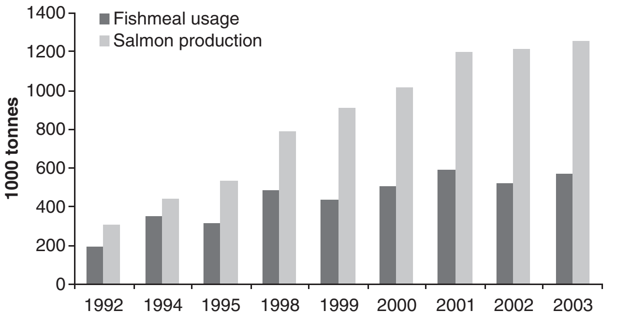

Figure 4. Salmon production and fishmeal usage 1992 and 2003
Source: Tacon (2005)

from a number of sources as listed in Tacon (2005).[7] The figure indicates that the demand for fishmeal has become more elastic in salmon aquaculture. The same point was made by Kristofersson and Anderson (2005), although they used for figures for carnivorous aquaculture species in general, rather than salmon specifically.

3. Data

In order to estimate derived demand for fishmeal we use data from 12 large fishmeal-consuming countries: Canada, Chile, Denmark, France, Germany, Ireland, Italy, Japan, The Netherlands, Norway, the UK and the USA. All these countries have industrialised pork and poultry production, but only Canada, Chile, Ireland, Norway and the UK have sizeable intensive salmon production.[8] The data panels were comprised of annual data from the FAO and IFFO from 1977 to 2006. With 30 annual observations from the five and seven countries in the two datasets, 120 and 168 observations, respectively, are available for estimations from each dataset. Prices of fishmeal and the other feed inputs are unit values based on country trade data. Fishmeal consumption is defined as[9,10]

$$\text{production} + (\text{imports} - \text{exports}) + (\text{initial stocks} - \text{ending stock}).$$

In the five salmon-producing countries, the size of salmon aquaculture production relative to pork and poultry production varies greatly. For the data period, the mean ratio of salmon aquaculture production to the sum of pork and poultry

[7] The specific sources are New and Csavas (1995), Pike (1998), Tacon (1998), Tacon and Forster (2003), New and Wijkstrom (2002), IFOMA (2000), Tacon (2003, 2004), Pike and Barlow (2003), Pike (2005) and Tacon (2005).

[8] China is the world's largest fishmeal importer, and as such it would have been desirable to include it in the dataset. Because of unreliable data we have chosen to omit China.

[9] Stock data are only included for the major fishmeal producers, Norway and Chile, with data from International Fish Meal and Fish Oil Organization (IFFO).

[10] A few unrealistic figures related to fishmeal consumption in earlier years for Chile and Norway led us to believe that there are some measurement errors associated with the fishmeal consumption construct in these years for these two countries, in particular for Chile. This is dealt with in the econometric estimation by smoothing a few observations early in the sample.

production is 6.6% for the five salmon-producing countries, with mean values of 1.4% for Canada, 25% for Chile, 2.9% for Ireland, 133% for Norway and 2.4% for the UK. The aquaculture–livestock production ratios may seem small for some of the countries, but one should take into account that, for each kilogram of feed, the salmon sector consumes 3–20 times more fishmeal than the pork and poultry sectors.[11]

Given the large number of ingredients used in salmon, pig and poultry feeds, a certain level of aggregation is inevitable. The list of feed inputs is very long and inclusion of all of them is not feasible, leading to multicollinearity issues and insufficient degrees of freedom. The studies of Peeters and Surry (1993) and Peeters (1995) provide a departure point for aggregating demand for feed ingredients, and lead us to include three general categories of feed inputs: protein meals, vegetable oils and cereals.

4. Empirical Model Specification

The general specification of the fishmeal demand model is

$$X_{\mathrm{FM}} = (W_{\mathrm{FM}}, W_{\mathrm{SM}}, W_{\mathrm{C}}, W_{\mathrm{SO}}, Y_{\mathrm{PP}}, Y_{\mathrm{S}}, T), \qquad (1)$$

where X is the quantity demanded, W denotes prices (unit values), Y is the sectoral production, T is a time trend variable representing technical change and the subscripts are as follows: FM = fishmeal, C = cereals, SO = soybean oil, SM = soybean meal, PP = pork and poultry sector and S = salmon (aquaculture) sector. Cereals and soybean oil are first and foremost used as energy sources in feeds, although cereals also provide some proteins, whereas soybean meal is mainly used for its protein content in the same way as fishmeal. Soybean meal and soybean oil prices act as indicators for vegetable meal and oil prices. The soybean-derived products are traded more frequently than similar vegetable oilseed products, and they therefore represent a more consistent choice across countries. Additionally, both of them have dominant positions in their respective markets, which make them natural candidates for market indicators. The price of cereals is based on an aggregate for cereals from FAO trade statistics.

As the growth rates for pork and poultry production are highly correlated, it is difficult to separate their impacts on the fishmeal market. It is therefore assumed that the pork and poultry production can be represented as an aggregated meat-producing sector, Y_{PP}. The assumption should not be unreasonable as both the pork and poultry sectors have feed formulations based on least cost with several alternatives to fishmeal and similar feeding technologies.

The model specification implies that we estimate the aggregate demand of a cost-minimising multi-output sector producing pork and poultry and salmon outputs. The technology is assumed to be non-joint so that the cost of producing all outputs can be expressed as the sum of independent cost functions for each output, i.e.

[11] The ratio interval is based on typical inclusion rates of fishmeal in salmon, pig and poultry feeds based on Tacon (2005). The lower bound is calculated with a 3% average inclusion rate of fishmeal in pig and poultry feeds and 50% average inclusion rate in salmon feed, whereas the equivalent figures for the upper bound are 2% and 40%. These figures should be interpreted as historical inclusion rates.

$$C(W_{\rm FM}, W_{\rm SO}, W_{\rm C}, W_{\rm SO}, Y_{\rm PP}, Y_{\rm S}) = C^{\rm PP}(W_{\rm FM}, W_{\rm SM}, W_{\rm C}, W_{\rm SO}, Y_{\rm PP}, Z) + C^{\rm S}(W_{\rm FM}, W_{\rm SM}, W_{\rm C}, W_{\rm SO}, Y_{\rm S}, Z),$$

where Z is a vector of variables that allows for shifts in the production function.

As noted in the data section, disaggregated data of fishmeal demand from the pork and poultry sector and the aquaculture sector are not available, although that availability would be desirable as it would allow us to estimate the sector-specific demand directly. Without sector-specific data there is a separability issue, as it is not possible to observe the amount of fishmeal that goes to either of the two sectors. This implies that we cannot identify the sector-specific production functions for meat and salmon, i.e.

$$Y_{\rm PP} = f_{\rm PP}(X_{\rm FM}, X_{\rm SM}, X_{\rm C}, X_{\rm SO}, Z) \quad \text{and} \quad Y_{\rm S} = f_{\rm S}(X_{\rm FM}, X_{\rm SM}, X_{\rm C}, X_{\rm SO}, Z),$$

which constitute the basis for estimating derived demand elasticities for the individual sectors. Our strategy to overcome this problem is to estimate fishmeal demand from countries that only have meat production separately from those countries that have both meat and salmon production.

The econometric specification of the model of aggregate fishmeal demand is given by the following log–log model:

$$\ln X_{{\rm FM},i,t} = \beta_{0,i} + \beta_{X,i} \ln X_{{\rm FM},i,t-1} + \beta_{{\rm FM},i} \ln W_{{\rm FM},i,t} + \beta_{{\rm SM},i} \ln W_{{\rm SM},i,t} + \beta_{{\rm C},i} \ln W_{{\rm C},i,t} + \beta_{{\rm SO},i} \ln W_{{\rm SO},i,t} + \beta Y_{{\rm PP},i} \ln Y_{{\rm PP},i,t} + \beta Y_{{\rm S},i} \ln Y_{{\rm S},i,t} + \beta_{T,i,t}, \tag{2}$$

where subscript t (=1976, 1978,..., 2006) denotes time and i (={Canada, Chile, Denmark, Germany, France, Ireland, Italy, Japan, The Netherlands, Norway, UK, USA}) denotes country. The term involving salmon production, $\beta_{{\rm YS},i} \ln Y_{{\rm S},i,t}$, is dropped from the estimation of the seven meat-producing countries. Note that the parameter vector β_i is allowed to be country specific, as implied by the subscript i. The own-price elasticity of fishmeal demand in country i is

$$e^{\rm SR}_{{\rm FM},i} = \partial \ln X_{{\rm FM},i,t} / \partial \ln W_{{\rm FM},i,t} = \beta_{{\rm FM},i}$$

in the short run, where superscript SR represents short run, and

$$e^{\rm LR}_{{\rm FM},i} = \beta_{{\rm FM},i} / (1 - \beta_{x,i})$$

is the long-run own-price elasticity.

If price elasticities are different between the pork and poultry and salmon sectors, the estimated country-specific elasticities will be influenced by the relative level of pork and poultry production to salmon production. For example, if own-price elasticity of fishmeal demand is lower in the salmon sector than in the pork and poultry sector, then the 'average' elasticity will decline as salmon production increases relative to that of porks and poultry.

5. The Shrinkage Estimator

Estimation of separate demand models gives the greatest degree of flexibility with respect to obtaining country-specific elasticity estimates. Earlier studies have demonstrated that such regression models often provide implausible elasticity estimates, for example, positive own-price elasticities (Atkinson and Manning, 1995). The 'shrinkage' estimator represents a compromise between separate and pooled demand models, as it shrinks estimates from separate regression models toward a population average. Although the shrinkage estimator allows for slope coefficient heterogeneity, it imposes a common probability distribution on the generation of the true coefficient values across the countries (Maddala *et al.*, 1997). The common probability distribution involves a common mean μ and non-zero covariance matrix Σ, from which the true parameter values of the demand models are drawn for each country. The coefficients estimated by the shrinkage method will be a weighted average of the overall pooled estimate and separate estimates from each country.

In its most general form the linear demand model, which is a random coefficients model, is specified as

$$y_i = X_i\beta_i + u_i, \quad i = 1, 2, \ldots, N, \tag{3}$$

where y_i is a $T \times 1$ vector, X_i is a $T \times k$ matrix of observations on the k explanatory variables, β_i is a $k \times 1$ vector of parameters and u_i is a $T \times 1$ vector of random errors, which is distributed as $u_i \sim N(0, \sigma_i^2 I)$.

We assume that

$$\beta_i \sim \mathrm{IN}(\mu, \Sigma), \tag{4}$$

or equivalently that

$$\beta_i = \mu + v_i, \tag{5}$$

where $v_i \sim N(0, \Sigma)$. Equation (5) specifies the prior distribution of β_i in the Bayesian framework. The variance–covariance matrix Σ measures heterogeneity. From equations (4) and (5) we see the posterior distribution of β_i depends on μ and Σ. If μ and Σ are not known, priors must be specified. When our (so to speak) parameters of interest, μ, σ_i^2 and Σ, are known, the posterior distribution of β_i is normal with mean and variance given by

$$\beta_i^* = \left(\frac{1}{\sigma_i^2}X_i'X_i + \Sigma^{-1}\right)^{-1}\left(\frac{1}{\sigma_i^2}X_i'X_i\hat{\beta}_i + \Sigma^{-1}\mu\right), \tag{6}$$

$$V(\beta_i^*) = \left(\frac{1}{\sigma_i^2}X_i'X_i + \Sigma^{-1}\right)^{-1} \tag{7}$$

respectively. $\hat{\beta}_i$ is the OLS estimate of β_i.

If the matrix X_i includes lagged values of y_i, the normality of the posterior distribution of β_i^* holds only asymptotically and under the usual regularity conditions assumed in dynamic regression models.

In the empirical Bayes approach we use the following sample-based estimates of the parameters of interest, μ, σ_i^2 and Σ in equation (6):

$$\mu^* = \frac{1}{N}\sum_{i=1}^{N}\beta_i^*, \tag{8a}$$

$$\hat{\sigma}_i^2 = \frac{1}{T-k}(y_i - X_i\beta_i^*)'(y_i - X_i\beta_i^*), \tag{8b}$$

$$\Sigma^* = \frac{1}{N-1}\sum_{i=1}^{N}(\beta_i^* - \mu^*)(\beta_i^* - \mu^*)'. \quad (8c)$$

The prior mean μ^* is an average of β_i^*, the estimate of the prior variance Σ^* is obtained from deviations of β_i^* from their average μ^* and the estimate of σ_i^2 is obtained from the residual sum of squares using β_i^*, not the OLS estimator $\hat{\beta}_i$.

Equations (8) are estimated iteratively. In the initial iteration, the OLS estimator $\hat{\beta}_i$ is used to compute μ^*, σ_i^2 and Σ^*. To improve convergence and to allow for adjustment of the weight of the individual units i in the estimation, equation (8c) is modified as

$$\Sigma^* = \frac{1}{N-1}\left[R + \sum_{i=1}^{N} w_i(\beta_i^* - \mu)(\beta_i^* - \mu)'\right], \quad (8c')$$

where R is a diagonal $k \times k$ matrix with small values along the diagonal (e.g. 0.001) and w_i is a weight that determines the influence of unit i in the estimation of Σ^* ($\sum_i w_i = N$). According to a Monte Carlo study by Hu and Maddala (1994), the iterative procedure gives better estimates in the mean-squared sense for both the overall mean μ and the heterogeneity matrix Σ than two-step procedures.

6. Empirical Results

Our focus is on the estimation of long-run demand elasticities for fishmeal. We first present the OLS estimates and then the shrinkage elasticities.[12]

Table 1 shows the estimated long-run elasticities for each of the salmon- and meat-producing countries estimated individually using OLS. The upper half of Table 1 reports the results as averages of the salmon-producing countries, whereas the lower part covers the meat-producing countries. From the estimated OLS elasticities, it is clear that the results often are neither particularly plausible nor very significant. For example, several of the own-price elasticities are positive. This is also found in other studies that for other sectors first estimate individual demand elasticities by OLS, and then move on to estimate shrinkage elasticities (Baltagi and Griffin, 1997; Maddala *et al.*, 1997; Baltagi *et al.*, 2000) Consequently, we choose not to dwell on the results from the OLS estimation and move directly on to the results from the shrinkage estimator.

Table 2 presents the results from the shrinkage estimation, using the OLS estimates from Table 1 as starting values. An inspection of Table 2 reveals that the shrinkage estimator removes much of the variation among the estimated parameters; a result of the estimated OLS coefficients being ‘shrunk’ toward the pooled mean. However, the majority of the estimated elasticities are significant. In relation to the scarcity issue of marine proteins, a key variable is the fishmeal price. If the

[12] It should be noted that we also tried other estimators, including several instrumental variable specifications with lagged explanatory variables and global supply of fish used for reduction as instruments. However, these produced implausible elasticity estimates. Fixed and random effects panel data estimators also produced implausible results compared with those we present here.

Table 1
Estimates of long-run elasticities for fishmeal demand using OLS estimator

Country	ε_{WFM}	ε_{WSM}	ε_{WC}	ε_{WSO}	ε_{YPP}	ε_{YS}	ε_{T}
Salmon							
Canada	0.673 (1.368)	−0.116 (−0.206)	−0.135 (−0.248)	0.252 (0.441)	1.312 (1.144)	0.142 (1.824)	−0.043 (−0.909)
Chile	−0.414 (−0.785)	−0.014 (−0.033)	0.427 (0.586)	0.466 (1.104)	0.427 (0.690)	0.071 (1.824)	0.005 (0.074)
Ireland	−0.259 (−0.161)	−0.400 (−0.212)	−0.132 (−0.121)	1.063 (1.245)	1.515 (0.556)	0.647 (1.824)	−0.133 (−1.722)
Norway	0.576 (1.297)	0.452 (1.075)	−0.459 (−1.301)	−0.544 (−1.838)	−0.678 (−0.423)	0.590 (1.824)	−0.005 (−0.082)
UK	−0.503 (−0.984)	0.447 (0.804)	−0.032 (−0.071)	−0.087 (−0.364)	1.078 (2.231)	0.030 (1.824)	−0.022 (−1.135)
Meat							
Denmark	−0.069 (−0.177)	0.258 (0.497)	−0.375 (−1.051)	0.320 (1.247)	1.630 (1.238)	0.676 (1.824)	−0.021 (−0.516)
France	0.258 (0.811)	−0.061 (−0.130)	−1.074 (−15.725)	0.177 (0.666)	−1.679 (−1.644)	1.337 (1.824)	−0.029 (−1.312)
Germany	0.727 (0.795)	−0.923 (−0.714)	−0.804 (−0.832)	−0.105 (−0.114)	1.884 (1.143)	0.580 (1.824)	−0.128 (−6.196)
Italy	−0.661 (−1.214)	0.064 (0.138)	0.505 (1.487)	−0.078 (−0.231)	−3.187 (−1.645)	0.817 (1.824)	0.013 (0.575)
Japan	−0.083 (−0.386)	−0.195 (−0.948)	−0.133 (−0.557)	−0.104 (−0.751)	0.108 (0.246)	0.096 (1.824)	−0.021 (−8.623)
The Netherlands	−2.278 (−1.978)	1.569 (1.570)	−0.161 (−0.169)	0.637 (0.843)	−0.430 (−0.305)	0.309 (1.824)	0.054 (1.391)
USA	−1.387 (−6.478)	0.851 (3.051)	−0.262 (−1.590)	0.059 (0.333)	−0.489 (0.685)	0.193 (1.824)	0.004 (0.147)

Table 2

Estimates of long-run elasticities for fishmeal demand using shrinkage estimator

Country	ε_{WFM}	ε_{WSM}	ε_{WC}	ε_{WSO}	ε_{YPP}	ε_{YS}	ε_{T}
Salmon							
Canada	−0.219 (−5.43)	0.162 (5.68)	−0.304 (−9.78)	0.048 (2.80)	0.455 (31.21)	0.291 (1.82)	−0.047 (−4.36)
Chile	−0.397 (−8.77)	0.321 (9.46)	−0.156 (−4.33)	0.121 (6.49)	0.463 (35.20)	0.139 (1.82)	−0.033 (−2.31)
Ireland	−0.186 (−3.40)	0.140 (3.54)	−0.331 (−8.03)	0.040 (1.93)	0.469 (29.18)	0.333 (1.82)	−0.062 (−5.03)
Norway	−0.100 (−1.59)	0.082 (1.79)	−0.392 (−8.27)	0.017 (0.73)	0.498 (35.20)	0.429 (1.82)	0.000 (0.01)
UK	−0.362 (−8.99)	0.289 (10.25)	−0.187 (−5.91)	0.104 (6.39)	0.460 (37.07)	0.165 (1.82)	−0.037 (−4.58)
Meat							
Denmark	−0.048 (−0.58)	0.030 (0.49)	−0.438 (−6.97)	−0.007 (−0.25)	0.487 (39.28)	0.467 (1.82)	−0.005 (−0.52)
France	0.071 (0.87)	−0.066 (−1.09)	−0.541 (−9.05)	−0.048 (−1.66)	0.504 (40.46)	0.585 (1.82)	−0.051 (−7.45)
Germany	−0.229 (−2.56)	0.174 (2.54)	−0.297 (−4.27)	0.055 (1.75)	0.464 (55.63)	0.292 (1.82)	−0.072 (−6.19)
Italy	−0.082 (−0.98)	0.050 (0.79)	−0.414 (−6.46)	−0.001 (−0.04)	0.470 (39.21)	0.428 (1.82)	−0.030 (−3.66)
Japan	−0.281 (−4.64)	0.236 (5.19)	−0.245 (−5.20)	0.086 (3.84)	0.494 (67.02)	0.261 (1.82)	−0.015 (−4.02)
The Netherlands	−0.231 (−4.16)	0.184 (4.71)	−0.290 (−6.97)	0.061 (2.98)	0.479 (28.15)	0.300 (1.82)	−0.012 (−1.00)
USA	−0.232 (−3.01)	0.174 (2.95)	−0.294 (−4.86)	0.053 (1.93)	0.459 (49.13)	0.287 (1.82)	−0.041 (−4.63)

t-values in parentheses, calculated using the delta method.

feed sector depends strongly on marine proteins one would expect that fishmeal demand is own-price inelastic. The estimated own-price elasticities, ε_{WFM}, from the shrinkage estimation are inelastic for all countries, as they vary from −0.397 for Chile to 0.071 for France. The price elasticity for France, which has the wrong sign, is not significant.

The own-price elasticities suggest that demand for fishmeal is inelastic both for the salmon- and meat-producing sectors. We expected that fishmeal demand from the salmon aquaculture sector would be more inelastic than that from pork and poultry sectors. However, similarity of the parameters might be a result of the shrinkage estimator removing 'too much' of the variation. This will be apparent if one compares the minimum and maximum parameter values of the estimated elasticities for the different variables. For this reason we do not attach much importance to the lack of cross-country differences among the estimated coefficients.

Historically, the fishmeal price has been strongly linked to the soybean meal price, as both of them are used as protein inputs in animal and aquaculture feeds (Asche and Tveterås, 2004). This link is evident from the estimates for the soybean meal cross-price elasticities, which are mostly positive, varying between −0.066 for France and 0.321 for Chile. The soybean meal coefficients are similar in magnitude to the own-price elasticities, only slightly smaller, and with the opposite sign. Positive cross-price elasticities imply that soybean meal is a substitute, although the parameter magnitudes imply that there is far from a 1 : 1 relationship between their prices.

The other two feed inputs included in the regression as determinants of fishmeal demand are the prices for cereals and soybean oil. From the results, cereal appears to be a complement to fishmeal as the estimated cross-prices elasticities range from −0.541 to −0.156, whereas soybean oil appears as a substitute with cross-price elasticities ranging from 0.455 to 0.504. For feed formulation, cereals clearly complement protein inputs such as fishmeal. It is more ambiguous whether soybean oil is a substitute for or a complement to fishmeal. In the estimated model, one can interpret soybean oil as a representative of other vegetable oils, as many of these oils share similar price trends due to similar uses (i.e. as an energy source in feeds). Vegetable oils can be both substitutes for and complements to fishmeal, as, on the one hand, proteins, such as fishmeal, also have a fat content for which oils are used, whereas, on the other, proteins and fats are complements in feeds. According to the results, however, soybean oil's role as a substitute dominates.

The growth in fishmeal demand caused by increased production of pork and poultry and by increased production of salmon aquaculture is represented by the elasticities ε_{YPP} and ε_{YS}. Both of these elasticities are positive and highly significant implying that increased animal and aquaculture production lead to increased demand pressure on fishmeal resources. The coefficients for poultry and pork production range from 0.455 to 0.504, i.e. quite similar, whereas the coefficients for salmon production range from 0.139 to 0.585. Some comments on these elasticities are warranted. First, the estimates for elasticity of fishmeal consumption with respect to salmon production are primarily relevant for the salmon-producing countries, but the estimated parameters are also included for the meat-producing countries, as shown Table 2. Shrinkage estimation does not allow the suppression of parameters to zero and, consequently, the inclusion of meat-producing countries introduces a bias in the estimation. We accept the trade-off as the shrinkage estimator produces results that are far more reasonable than all other models that were estimated, including instrumental variable estimation and other panel data methods such as fixed effects and random effects. However, because of the bias, we put less emphasis on the cross-country differences and more on the average level of the estimated elasticities. As was pointed out above, this is also reasonable as little cross-country variation remains when using the shrinkage estimator.

Second, the estimated production elasticities, $\varepsilon_{\mathrm{YPP}}$ and $\varepsilon_{\mathrm{YS}}$, are substantially higher for pork and poultry than for salmon. At first sight, this might seem unreasonable as we have argued that the aquaculture sector is the one more dependent on fishmeal. However, examining Figure 1 makes a couple of differences clear. Pork and poultry production is many times higher than salmon production. Hence, a 1% increase in the meat variable represents volumes that are many times larger than a 1% increase in salmon production. As a result, it is reasonable that the estimated coefficient is higher for pork and poultry. Furthermore, the influence on fishmeal demand due to growth in salmon aquaculture is substantial because salmon production has a higher growth rate than pork and poultry.

Finally, we examine the long-run time trend, ε_T, representing the influence of technological change on fishmeal demand. This varies between −0.072 and 0.000, indicating that, for most countries in the panel, fishmeal demand has been declining over time, controlling for all the other variables. The negative time trend indicates substitution away from fishmeal in feed formulations.

7. Conclusions

Global demand for meat and fish is expected to continue to increase due to economic and population growth (e.g. Delgado *et al.*, 1997). The promise of aquaculture, ‘the blue revolution’, is to meet the global demand for fish (*The Economist*, 2003). Figures from FAO indicate that aquaculture is already supplying over 50% of the fish people eat. However, there is a fear that aquaculture is unsustainably using wild fish resources for fish feed. To address this concern we have estimated a demand model for fishmeal that sheds some light on the link between aquaculture and pelagic fisheries. For a carnivorous species like salmon that is targeted for relatively well-paying markets the use of fishmeal tends to be substantial. The question is then what will happen with pressured pelagic fish stocks if aquaculture production continues to grow.

From the results, we find that fishmeal demand of salmon aquaculture is not sensitive to rising prices of marine proteins. This suggests that fishmeal consumption is more likely constrained by limited supply rather than high prices. Furthermore, the results corroborate that increasing salmon production leads to increased demand for fishmeal. For every per cent increase in salmon production, demand for fishmeal from these same countries tends to increase around 0.2% to 0.4%. These findings appear to support the existence of a fishmeal trap. Further examination, however, reveals that high prices and limited supply seem to be inducing the development of feed technologies less reliant on fishmeal.

The relationship between salmon production and fishmeal usage is far from 1 : 1. Production elasticities of 0.2–0.4 imply that the average fishmeal usage per kg of fish produced decreases when salmon production increases. These production elasticities themselves reflect the effects of technological change and substitution effects.

Moreover, the negative time trend also indicates substitution away from fishmeal. A negative trend for fishmeal usage is also found for the pork and poultry-producing sectors. Both of these results, i.e. the relatively low production elasticities and the negative time trend, imply that fishmeal usage per kg of fish farmed is falling. This implies that salmon aquaculture has been able to expand production by reducing its dependence on marine proteins, as observed more broadly for aquaculture in Kristofersson and Anderson (2005).

Consequently, the estimated fishmeal demand model does not necessarily support the belief that growth of livestock and aquaculture will lead to some sorts of fishmeal trap. The 'mis-alignment' between fishmeal and soybean meal prices observed in later years compared with their historically close relationship, might reflect that it takes time to introduce less fishmeal-dependent feed technologies. Meanwhile, growth in animal and aquaculture production may temporarily put pressure on scarce fishmeal resources. This tentative interpretation is not at odds with the empirical results, even if the model does not set out to capture the dynamics of fishmeal demand and technological change. Moreover, if farmed high-value species like salmon is to remain competitive relative to other farmed fish less reliant on marine proteins and meat products, reduction in fishmeal inclusion rates is inevitable. From 2000 to 2007, salmon and trout production has been increasing 6% annually and consequently one must assume that fishmeal use is diminishing.[13]

A limitation of the study is that we are unable to identify structural differences between the meat- and salmon-producing sectors. Undoubtedly, aquaculture has displaced parts of the fishmeal consumption of the livestock sector, as evident from Figure 3. With a 57% share of fishmeal consumption aquaculture has become the dominant player. The dramatic increase in fishmeal prices, as shown in Figure 2, should also be seen as a result of increased competition between livestock and aquaculture for marine proteins. Although different estimators were applied in an effort to capture heterogeneity between the two sectors, including instrumental variables and other panel data techniques, the attempts were marred by implausible parameter estimates. The shrinkage estimator, while allowing for heterogeneity among the countries, also concentrates the estimated parameters towards the pooled means for the various countries included. This means that the model is not very useful in explaining the displacement of the livestock sector in the fishmeal market.

When discussing rising prices as a manifestation of demand pressure, China's role should not be underestimated. As with many other commodities prices, the economic growth in China has fuelled global fishmeal demand. Fishmeal is used extensively in both aquaculture and livestock sectors in China. Unfortunately, reliable statistics from China are not available making it extremely difficult to determine the relative importance of the various sectors consuming fishmeal. It is interesting to note from Figure 3, however, that although livestock's combined share is decreasing, the pork-producing sector's share of fishmeal consumption has only been modestly affected. One may speculate whether this is because of China's increasing importance in the global fishmeal market.

[13] Regulations and disease outbreaks seem to have been the most important factors restricting growth during this period.

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