<u>**Working Paper No. 53/00**</u>

**On the relationship between aquaculture
and reduction fisheries**

by

**Frank Asche
Sigbjørn Tveterås**

Centre for Fisheries Economics
Discussion paper No. 7/2000

On the relationship between aquaculture and reduction fisheries

Abstract

Traditional aquaculture has to a large extent used herbivore species with limited requirements for additional feeding. However, in intensive aquaculture production one farm carnivore species like salmon and also feeds herbivore species with fishmeal as this increase growth. This has lead to a growing concern that increased aquaculture production poses an environmental threat to the species targeted in reduction fisheries as increased demand increase fishing pressure. In this paper we address this question along two lines. First, under which management regimes may increased demand pose a threat to the species in question. Second, we investigate what is the market for fishmeal. Is fishmeal a unique product or is it a part of the larger market for oilmeals which includes soyameal? This is an important issue since the market structure for fishmeal is instrumental for whether increased aquaculture production may affect fishmeal prices, and thereby increase fishing pressure in industrial fisheries.

1. Introduction

During the last decades there has been a substantial increase in aquaculture production. The major cause for this development is new farming techniques allowing intensive aquaculture production.[1] This has led to a number of environmental concerns. These concerns can be divided into two main groups. The first group is pollution of the local and regional environment due to discharges from the production process, and in some cases destruction of habitat. These concerns tend to be local problems and can, at least in principle be solved by local regulation (Asche, Guttormsen and Tveterås, 1999).[2] The second concern is that growing aquaculture production leads to an increased fishing pressure on wild stocks due to increased demand for fishmeal, as fishmeal is an important part of the diet for cultured seafood (Naylor et al., 1998). This is an interesting observation, since it implies that the aquaculture industry creates environmental problems via the markets for its inputs. Moreover, since the market for fishmeal is global, this is then a global problem. This issue is also of interest because if it is a serious problem, it puts clear limits on how large aquaculture production can be.

In this paper we will focus on the impact of aquaculture on wild stocks through the demand for fishmeal. The analysis will be carried out in two parts. First, we will discuss how increased demand will affect landings and therefore fish stocks in a simple bioeconomic model. The effects of increased demand will be dependent on the management structure, and there are a number of management forms in the world's fisheries. However, these can be divided into three main groups; open access, sole-owner (or optimal management), and restricted open access. We will therefore analyze the effect of increased demand with three benchmarks based on these groups, where we use TAC (Total Allowable Catch) regulation as a representative restricted access fishery.[3]

Second, to what extent an increased demand for fishmeal will lead to increased demand for fish, will also depend on what is the market and uses for fishmeal. Fishmeal is not the only possible feed in aquaculture production and it is not used as feed only in aquaculture production, but also in agriculture.[4] Most cultured species can use at least some vegetable meals such as soyameal in their diet, and quite a few cultured species like carp, tilapia and American catfish is herbivore in nature. However, fishmeal is increasingly used in their diet to increase growth. Moreover, most fishmeal is currently used in agriculture as feed in poultry, pork and livestock production. It is therefore of substantial interest whether fishmeal is a unique product on its own or a part of the oilmeal market and a close substitute for e.g. soyameal. This is because the market structure is instrumental in determining how increased demand for feed from aquaculture producers can affect the price determination process for fishmeal.

2. Increased Demand and Fisheries Management

In this section we will first give a brief overview of the world's industrial fisheries. We will then turn to a simple bioeconomic model to illustrate the importance of management regime when demand increases, before we discuss the state of the most important industrial fisheries in this light.

2.1 Industrial fisheries

The world's reduction fisheries are mainly based on fisheries for small pelagic species.[5] Pelagic fish are used both for human consumption and for reduction, i.e. fishmeal and fish oil, but certain species are only fit for reduction due to their consistency, often being small, bony, and oily.

Normal yearly catches in the 1990s with the main purpose of reduction to fishmeal amount to approximately 30 million MT (metric tons), giving an average of 6-7 million MT fishmeal. The main fishing nations in 1997, when the fishmeal production was 6.2 tonnes, are shown in Figure 1. Chile and Peru alone deliver over 50% of the global fishmeal production based on their rich fisheries of Peruvian anchoveta, Chilean jack mackerel, and South American pilchard. Other substantial producers are the Nordic countries Denmark, Iceland and Norway. Combined their fisheries produce 15% of the global fishmeal production.
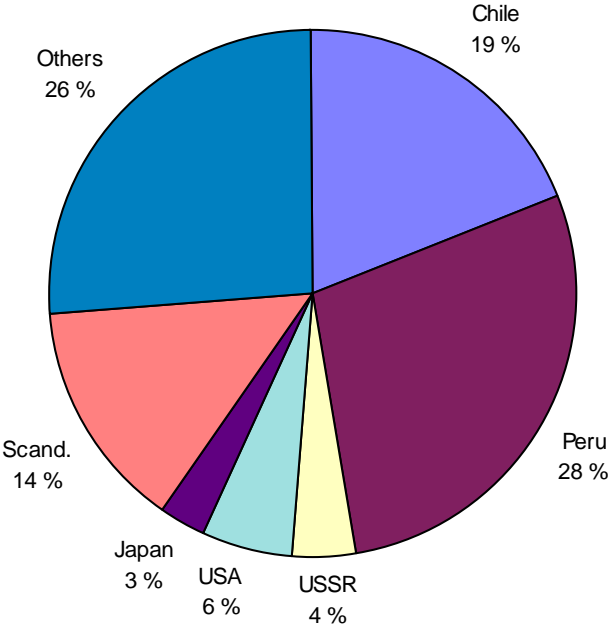

Figure 1. World fishmeal production in 1997 (FEO).

A characteristic of the pelagic fisheries is that the quantity going directly to human consumption stays relative stable, while the "surplus" that goes to reduction can vary quite dramatically (Hempel, 1999). Thus, in years when the catches are low, such as *El Niño* periods, the fishmeal industry is hard struck. Also, the pelagic fisheries have generally been described as fully exploited or over-exploited by the FAO (Grainger and Garcia, 1996).

Hence, a significant expansion of the global fishmeal production, beyond the 6-7 million MT that is normally produced, is not very likely.

2.2 A simple bioeconomic model

Let us then turn to the effect of increased demand in a fishery. We will only use the basic Gordon-Schaefer model, since introducing dynamics will not add essentially to our discussion of why increased demand for a species might be a threat against the species. If the fishery is regulated by a sole-owner, this agent will then have a zero discount rate in this simple form of the model. Textbook versions of this model cover the two most common institutional configurations in the fisheries economics literature in its simplest form, open access and optimal management (Homans and Wilen, 1997).[6] In addition to these two institutional configurations, we will also consider a regulated open access setting, since this is the most commonly observed management structure in the world's fisheries. We will here use a TAC as an example of the kind of a regulated open access fishery, but also other regulations like input factor restrictions or taxes can be used in place of or together with TACs. In this management setting one or more input factors are regulated, so that the fishery is generally regarded as biologically safe. However, one pays little attention to the economics of the fishery, and one typically observes over-capacity and rent dissipation. For simplicity we do not let the regulator be an endogenous part of the model as in Homans and Wilen (1997), but let the quota be set exogenously. This is probably not a very severe assumption since biological considerations tend to dominate economic issues when quotas are set.[7]

The net natural growth in the biomass is

(1) $\quad F(x) = rx(1 - x/k)$

where x is the biomass, r is the intrinsic growth rate and k is environmental carrying capacity. This function also gives the sustainable yield for different levels of the biomass. The value of the sustainable yield can be found by multiplying (1) with a price p, giving the sustainable revenue curve, TR. We will here, as in most analysis assume that the price is given from a world market, as certainly is reasonable for species that are used for fishmeal production.[8] Harvest H is given as

(2) $\quad H = \gamma x^{\alpha} E$

where γ is a catchability coefficient, α gives the strength of the stock effect and E is fishing effort. The fishery is in equilibrium when $F(x)=H$. Fishing cost is

(3) $\quad C = cE = cH/\gamma x^{\alpha}$

where c is the unit cost of fishing effort. Total profits or rent are

(4) $\quad \Pi = pH - cE$

This model has two equilibria: Under open access all rents are dissipated, and the biomass is at the level x^{∞}. Under rent maximization the biomass is at the level x^{0}. This is graphed in Figure 2, where the sustaninable revenue curve, TR, is shown together with the cost curve, C. As one can see, $x^{\infty} < x^{0}$, and one can also show that effort in an open access fishery is higher than in an optimally managed fishery, i.e. $E^{\infty} > E^{0}$. Under regulated open access, total harvest is determined by a quota Q. This is typically determined mainly by biological considerations. This will then lead to a biomass at some target level, x^{Q}, which under our assumptions are set without any economic considerations.
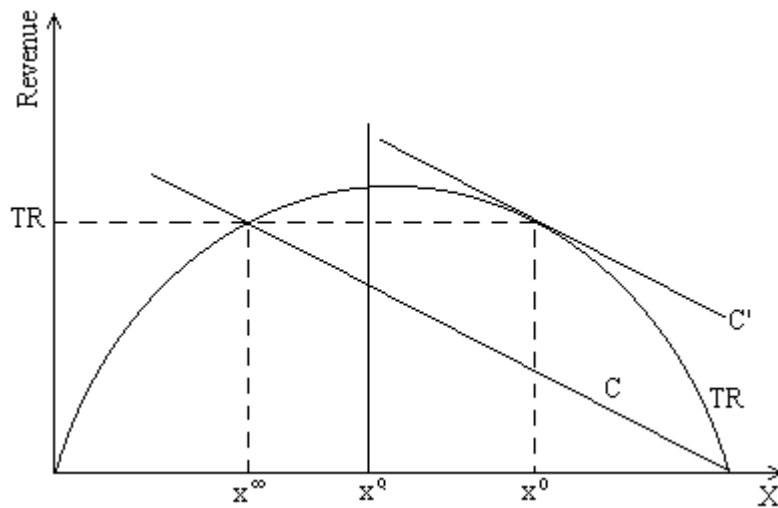
Figure 2. Total revenue and catches under open access, quotas regulations and sole owner in a Gordon-Schaefer model.

Assume then that the price increases due to increased demand at the world market. This will lead to an increase in the value of the natural growth of the fish stock and the harvest. This is introduced in the Figure 3 with the new sustainable revenue schedule, TR'. In the cases when the fishery is in open access or regulated by a sole owner, the increased value of the fish will lead to an increase in effort and to a decrease in the biomass. Under open access, for most stocks this will also lead us further up on the backward-bending part of the supply schedule. Lower landings will then give even higher prices and put further pressure on the stocks. At some point cost will prevent more effort, but in many fisheries this might be at very low levels of biomass. In particular, pelagic stocks with weak stock effects (i.e. an α parameter close to zero) can be driven down to very low levels.[9] This is important here, since many of the stocks targeted in reduction fisheries are pelagic. In the case with optimal management, landings will respond to the increased prices. However, the biomass will always be higher than *k/2*, or the biomass associated with Maximal Sustainable Yield (MSY), which traditionally has been the management criterion advocated by biologists. One can then hardly argue that the fishery

poses a threat to the stock.[10] If the fishery is regulated by a quota that is set without paying

attention to economic factors, the quota remains the same, the biomass remains the same, but

the value of the catch increases. Hence, we have the obvious conclusion that if the fishery is

not allowed to respond to economic incentives, increased prices due to increased demand will

not have any effect. Accordingly, the real problem is in the open access scenario, since

increased demand for a species in this scenario might lead to serious depletion of the stock,

and will increase the risk of extinction. The model outlined here allows the stock to be driven

down to very low levels, although not to become extinct. However, it is clear that with very

low stock levels the species also becomes substantially more vulnerable to changes in other

factor like water temperature, salinity, etc. that are not accounted for in the model. In more

general models, one may also increase the probability for extinction.
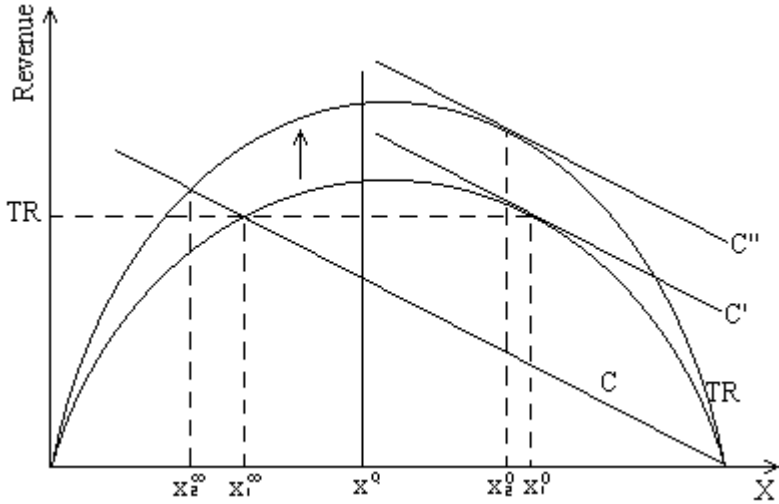

Figure 3. Effects of increased fish prices on catches and total.

2.3 The management of industrial fisheries

The analysis above indicates that increased demand for any species will mainly be a problem

if the fishery is not managed, i.e. is operated as an open access fishery. How is then the

management situation for the most important stocks used in industrial fisheries? Most of the world's fisheries for reduction are carried out in relatively few countries, with Peru and Chile as the most important (see Figure 4). The stocks of Peruvian anchoveta and Chilean jack mackerel have shown their vulnerability both due to the weather phenomenon *El Niño* and poor fisheries management. However, the fisheries management has improved over the last decade, with increasingly stricter regulations on inputs.[11] The most important tools used in Chile and Peru today are limiting access, quotas, input factor regulations and closures that are imposed on the fisheries in certain periods and certain areas. The industrial fisheries in the Nordic countries are regulated by TACs, and often additional restrictions. Due to different national interests these TACs often exceed biologically based advice. However, the overall state of the fisheries for reduction in the Nordic countries has improved substantially after herring stock collapses in the late 1960s and early 1970s, and several of these stocks have been rebuilt to the levels before the collapses. In the US, the menhaden fishery is the main industrial fishery, and also here the fishery is regulated with a TAC.
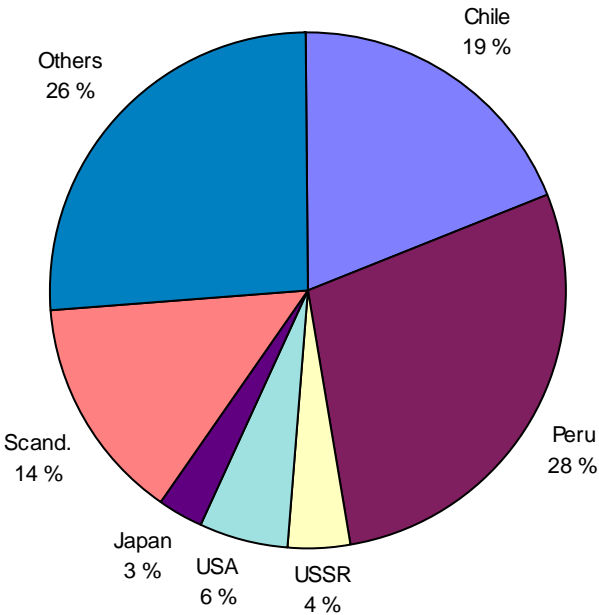

Figure 4. World fishmeal production in 1997 (FEO).

A first glance may indicate that the management situations for the most important pelagic fisheries are not too bad, and that open access is not a correct description. However, quotas tend to be high and one may often question whether the state of the fish stocks has the main priority when the quotas are set. Hence, it is not clear that the situation is very different from what it would be under open access. Many of these fisheries might as such be good examples of Homans and Wilen's (1997) notion that management is an endogenous part of the fishery.[12] Whether increased demand for fishmeal from a growing aquaculture industry is harmful for the state of the fish stocks that are targeted in industrial fisheries will then to a large extent depend on the market structure for fishmeal.

3. The market

We will now turn to the market for fishmeal. What is the market is an important question since this to a large extent will determine whether increased demand from aquaculture will affect prices with poor management of the stocks. In this section we will first provide a brief discussion of the world's oil meal markets and our data. We will then outline the methodology we use to delineate the market before we discuss the empirical results.

3.1 The world's oilmeal markets and data

There is little doubt that the markets for fishmeal are global. In fact, this is a main part of the criticism against the aquaculture industry, as it is the prime example that negative environmental effects are global and not only local. However, the aquaculture industry is far from the only user of fishmeal. In Figure 5, the main sectors that use fishmeal are shown for 1997. As one can see, aquaculture is relatively small, using about 17% of the production. Moreover, for most of the species that use fishmeal as feed, this is only a part of their diet. Other oilmeals, with soyameal as the largest also make up a major share. If one look at the

total market for oilmeals, global fishmeal production is rather minor compared to the total oilmeal production, as shown in Figure 6.
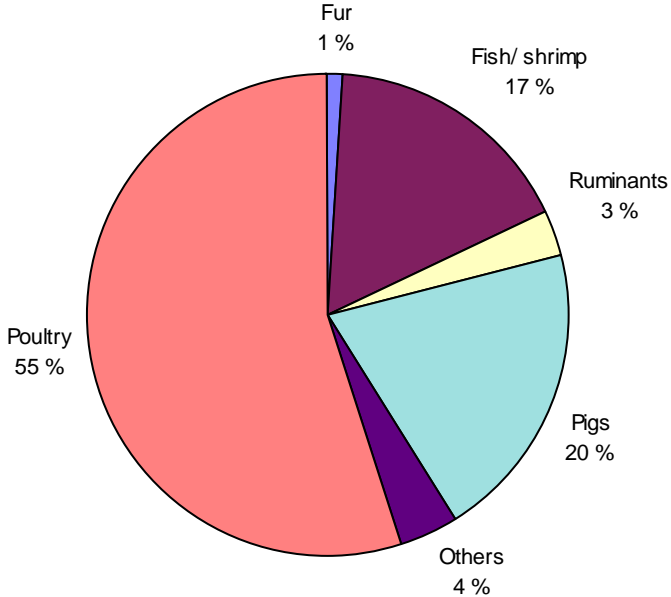

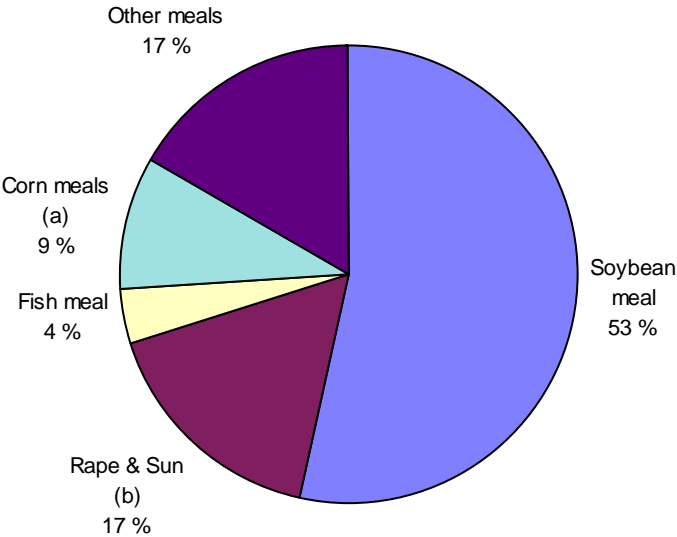**Figure 5.** Estimated total use of fishmeal (Pike, 1996).

Figure 6. World production of oilmeals 1996/97 (OW, 1999).
(a) Corngerm & cornglutenfeed. (b) Rapeseed meal & sunflower seed meal.

There are two main explanations why fishmeal is used in livestock production. One explanation stresses the uniqueness of fishmeal. Fishmeal has higher protein content than the other oilmeals, and also has a different nutritional structure. In particular, this is the case with respect to amino acids that may be positive for the general health of the animals. The other explanation emphasizes that fishmeal in general is cheap protein. These two explanations have very different implications for the price formation process for fishmeal. If fishmeal is used because it is unique, the price of fishmeal should be determined by the demand and supply for fishmeal alone. One the other hand, if fishmeal is used mainly because it is cheap protein, one would expect a high degree of substitutability between fishmeal and other oilmeals.[13] If the first explanation is correct, increased demand from aquaculture production for fishmeal are likely to increase prices, and therefore increase fishing pressure after poorly managed fish stocks. This might be true even if aquaculture's share of the demand is a low as 17%, since the additional demand from aquaculture then has to be met partly by aquaculture taking over fishmeal from other producers that find it too expensive and partly because the higher price increases production. However, if fishmeal is a close substitute for other oilmeals, one would not expect the price of fishmeal to be much influenced by increased demand from aquaculture, since the price is determined by total demand for oilmeals, of which demand from aquaculture is just a very tiny share.

To determine fishmeal's position in the oilmeal market, we will investigate its relationship to soyameal, since this clearly is the largest of the vegetable meals. The most obvious procedure would be to estimate demand equations and evaluate the cross-price elasticities. However, although there exist exchanges that give price data of good quality, it is extremely difficult if not impossible to obtain reasonable quantity data, as in most global markets.[14] Analysis of the relationships between prices will therefore be the preferred tool here, even though this does

not give as much information as demand analysis. However, it will allow us to determine whether the products are not substitutes, are perfect substitutes or are imperfect substitutes.

We use fishmeal and soyameal prices reported on a monthly basis from Europe and the US, in the period spanning from January 1981 to April 1999. The European prices are reported from Hamburg, and are denoted as Fish_Ham and Soya_Ham. In addition we use fishmeal prices from Atlanta, Georgia, denoted as Fish_Atl, and soyameal prices reported from Decatur, Illinois, denoted as Soya_Dec. The prices are shown in Figure 7. Note that the fishmeal prices are substantially higher than the soyameal prices. This is primarily because of the higher protein content. If one adjust for the protein content, most of this difference disappears. This period is interesting for at least two reasons: Firstly, there have been some extreme situations for the fishmeal production in this period due to low raw material supply, including *El Niños* in 1982-83, 1986-88, 1991-92 and finally in 1997-98, with the first and the last being the most severe. This makes it interesting to compare how the fishmeal and soyameal markets have interacted during these extreme periods. Secondly, the intensive aquaculture has experienced a tremendous growth in this period.[15] If the fishmeal primarily is demanded due to its special attributes, this should show up as the fishmeal and soyameal being different market segments during this period.
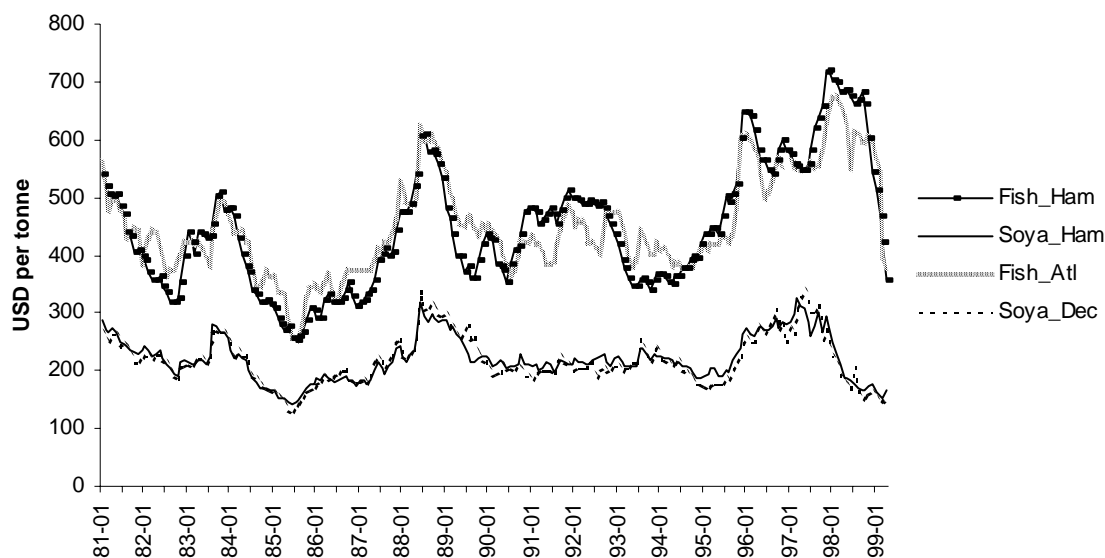
Figure 7. Monthly fishmeal and soybean meal price data from Hamburg (Ham), Atlanta (Atl) and Decatur (Dec) in the period of January 1981 to April 1999 (OilWorld).

Before a statistical analysis of the relationships can be carried out, we must investigate the time series properties of the data. Dickey-Fuller tests were carried out for the price series. The lag length was chosen as the highest significant lag. All prices are found to be nonstationary, but stationary in first differences (Table 1). Hence, cointegration analysis is the appropriate tool when investigating the relationships between the prices.

Table 1. Augmented Dickey-Fuller (ADF) tests for unit roots

Variable	Var. in levels	Var. in 1. diff.
Fish_Ham	-3.2486 (5)	-3.8090** (4)
Soya_Ham	-3.0824 (6)	-4.7883** (5)
Fish_Atl	-2.9874 (10)	-3.6270** (9)
Soya_Dec	-2.8635 (6)	-4.8965** (5)

*** indicates significant at a 1% significance level. The number in parenthesis is the number of lags used in ADF test, which is chosen on the basis of the highest significant lag out of 12 lags that were used initially. The tests for variables in levels include a constant and a trend, while in first differences only a constant is included.*

3.2 Market integration

Analysis of relationships between prices has a long history in economics, and many market definitions are based on the relationship between prices. For instance, in a book first published in 1838 Cournot states: "It is evident that an article capable of transportation must flow from the market where its value is less to the market where its value is greater, until difference in value, from one market to the other, represents no more than the cost of transportation" (Cournot, 1971). While this definition of a market relates to geographical space, similar definition are used in product space, but where quality differences plays the role of transport costs (Stigler and Sherwin, 1985; Sutton, 1991). The main arguments for why this is the case, are either arbitrage or substitution.

The basic relationship to be investigated when analyzing relationships between prices is

$$\ln p_{1t} = \alpha + \beta \ln p_{2t} \tag{5}$$

where α is a constant term (the log of a proportionality coefficient) that captures transportation costs and quality differences and β gives the relationship between the prices.[16] If $\beta=0$, there are no relationship between the prices, while if $\beta=1$ the Law of One Price holds, and the relative price is constant. In this case one can say that the goods in question are perfect substitutes. If β is greater than zero but not equal to one there is a relationship between the prices, but the relative price is not constant, and the goods will be imperfect substitutes.[17]

Equation (5) describes the situation when prices adjust immediately. However, often there will be a dynamic adjustment pattern, This can be accounted for by introducing lags of the two prices (Ravallion, 1986). It should here be noted that even when dynamics are introduced, the long-run relationship will have the same form as equation (5). One can also show that there is

a close relationship between market integration based on relationships between prices and aggregation via the composite commodity theorem (Asche, Bremnes and Wessells, 1999). In particular, if the Law of One Price holds the goods in question can be aggregated using the generalized commodity theorem of Lewbel (1996).

Since the late 1980s, one has become aware that when prices are nonstationary, traditional econometric tools cannot be used, since normal inference theory breaks down (Engle and Granger, 1987). Cointegration analysis is then the appropriate tool. In early studies, single equation Engle and Granger tests (Engle and Granger, 1987) were used. However, as these have several weaknesses, the system based Johansen test (Johansen, 1988) is currently the preferred tool. For instance, the Engle and Granger test do not allow testing of the *LOP* hypothesis, while this is easily done using the Johansen test.[18] Since our price series seems to be nonstationary, we will use this approach.

The Johansen test is based on a vector autoregressive (VAR) system. A vector, x_t, containing the N variables to be tested for cointegration is assumed to be generated by an unrestricted k^{th} order vector autoregression in the levels of the variables;

$$\mathbf{x}_t = \Pi_1 \mathbf{x}_{t-1} + ... + \Pi_k \mathbf{x}_{t-k} + \mu + e_t, \tag{6}$$

where each of the Π_i is a ($N{\times}N$) matrix of parameters, μ a constant term and $\varepsilon_t \sim iid(0,\Omega)$. The VAR system of equations in (6) written in error correction form (ECM) is;

$$\Delta \mathbf{x}_t = \sum_{i=1}^{k-1} \Gamma_i \Delta \mathbf{x}_{t-i} + \Pi_K \mathbf{x}_{t-k} + \mu + e_t \tag{7}$$

with $\quad \Gamma_i = -I + \Pi_1 + ... + \Pi_i$, $i = 1,...,k-1$ and $\Pi_K = -I + \Pi_1 + ... + \Pi_k$. Hence, Π_K is the long-run 'level solution' to (6). If x_t is a vector of $I(1)$ variables, the left-hand side and the

first (k-1) elements of (7) are $I(0)$, and the last element of (7) is a linear combination of $I(1)$ variables. Given the assumption on the error term, this last element must also be $I(0)$; $\Pi_K x_{t-k} \sim I(0)$. Hence, either x_t contains a number of cointegration vectors, or Π_K must be a matrix of zeros. The rank of Π_K, r, determines how many linear combinations of x_t are stationary. If $r=N$, the variables in levels are stationary; if $r=0$ so that $\Pi_K=0$, none of the linear combinations are stationary. When $0<r<N$, there exist r cointegration vectors—or r stationary linear combinations of x_t. In this case one can factorize Π_K; $-\Pi_K = \alpha\beta'$, where both α and β are ($N\times r$) matrices, and β contains the cointegration vectors (the error correcting mechanism in the system) and α the adjustment parameters. Two asymptotically equivalent tests exist in this framework, the *trace* test and the *maximum eigenvalue* test, of which the *trace* test is considered the more robust (Cheung and Lai, 1993).[19]

The Johansen procedure allows hypothesis testing on the coefficients α and β, using likelihood ratio tests (Johansen and Juselius, 1990). In our case, it is restrictions on the parameters in the cointegration vectors β which is of most interest. More specifically, in the bivariate case there are two price series in the x_t vector. Provided that the price series are cointegrated, the rank of $\Pi = \alpha\beta'$ is equal to 1 and α and β are 2x1 vectors. Of particular interest is the Law of One Price (LOP), which can be tested by imposing the restriction $\beta'=(1,-1)'$. In the multivariate case when all prices have the same stochastic trend, there must be n-1 cointegration vectors in the system and each cointegration vector must sum to zero for the LOP to hold. It then follows from the identification scheme of Johansen and Juselius (1992) that each cointegration vector can be represented so that all but two elements are zero. When the identifying normalization is imposed in the case with four price series, one representation of the matrix of cointegration vectors is:

$$\beta = \begin{bmatrix} 1 & 1 & 1 \\ -\beta_1 & 0 & 0 \\ 0 & -\beta_2 & 0 \\ 0 & 0 & -\beta_3 \end{bmatrix} \qquad (8)$$

That is, one can represent the system with *n* prices with *n*-1 pairwise relationships. If all β

parameters are equal to 1, the *LOP* holds for the whole system. Hence, in a market delineation

context, multivariate and bivariate tests can in principle provide the same information (Asche,

Bremnes and Wessells, 1999). However, the two approaches have different statistical merits.

Using a multivariate approach, one is exposed what Hendry (1995, p. 313) labels the "curse of

dimensionality" in dynamic models, since one with a limited number of observations and

thereby degrees of freedom will have to choose between number of lags and number of

variables. In bivariate analysis one is less exposed to this problem, but one may obtain several,

possible conflicting, estimates of the same long-run relationships. We will therefore estimate

both a multivariate system and bivariate systems.

Recently, a number of studies have used cointegration analysis to investigating relationships

between prices. Examples related to seafood products are Gordon, Salvanes and Atkins

(1993), Bose and McIlgrom (1996), Gordon and Hannesson (1996), Asche, Salvanes and

Steen (1997), Asche and Sebulonsen (1998) and Asche, Bremnes and Wessells (1999).

3.4 Empirical results

We start out our empirical analysis by performing a multivariate Johansen test for all prices,

i.e. the European and the US fishmeal and soyameal prices. The test is specified with four

lags, a restricted intercept and 11 seasonal dummies. The intercept is restricted to only enter

the long-run equations of the system.[20] A LM-test against autocorrelation up to the 12th order

cannot be rejected for the system with four lags.[21] Hence, four lags seem sufficient to include all dynamics. However, we cannot reduce the laglength further without getting problems with dynamic misspecification. The results from the multivariate test are reported in Table 2. The trace test concludes with 3 cointegration vectors. The max test concludes with two cointegration vectors at a 5% significance level, but with three at a 10% significance level. Given that all prices are cointegrated in the bivariate tests reported bellow, we therefore conclude with three cointegration vectors and one stochastic trend in the system. We find weak evidence against the LOP in the system as a likelihood ratio test distributed as $\chi^2(3)$ produces a test statistic of 8.33 with a *p*-value of 0.040. Hence, we can reject the null at a 5% level, but not at a 4% level.

Table 2. Multivariate Johansen tests of fishmeal and soyameal prices from Europe and USA.

H_o:	Max test	95% critical value	Trace test	95% critical value
p==0	55.82**	28.1	112.2**	53.1
p<=1	33.99**	22.0	56.38**	34.9
p<=2	13.84	15.7	22.39*	20.0
p<=3	8.65	9.2	8.65	9.2

* indicates significant at a 5% significance level while * indicates significant at a 1% significance level.

Given the *El Niños* and the increased demand for fishmeal from aquaculture in our data sample, parameter stability is also of interest. Clements and Hendry (1995) and Hendry (1995) argue that most parameter changes are in the intercept, so checking constancy of the constant term should be the focus of tests for parameter stability. In dynamic models like ours, this might also be important since if one is to investigate parameter stability for all parameters, one increases the likelihood substantially for dimensionality problems. We will therefore follow this approach and test against a structural break in the constant terms in January 1991, which

is approximately mid sample. By choosing mid sample as break point we get two *El Niños* in each of the samples. The test is distributed as *F*(3,185) and gives a test statistic of 1.32 with a *p*-value of 0.2649. Hence, this test does not provide any evidence against the null hypothesis of no structural break.

The results from the bivariate cointegration tests are reported in Table 3. The variables are denoted as Fish_Ham and Soya_Ham for fishmeal and soyameal prices reported from Hamburg, Fish_Atl for fishmeal prices in Atlanta and Soya_Dec for soyameal prices in Decatur. The *max* test and the *trace* test both give evidence of one cointegration vector for all pairs of prices. Hence, also these tests indicate that there is one stochastic trend in the system.

Table 3. Bivariate cointegration tests with 4 lags.

Variable 1	*Variable 2*	*Max test p==0*	*Max test p<=1*	*Trace test p==0*	*Trace test P<=1*	*LOP*	*Autocorr -elation*
Fish_Ham	Fish_Atl	20.71**	7.336	28.05**	7.336	0.0466*	0.1651
Fish_Ham†	Soya_Ham	20.13*	8.394	28.53**	8.394	0.4991	0.2270
Fish_Ham†	Soya_Dec	17.74*	6.479	24.22*	6.479	0.3402	0.6923
Fish_Atl†	Soya_Ham	49.69**	7.001	56.69**	7.001	0.7688	0.5811
Fish_Atl†	Soya_Dec	58.24**	6.261	64.5**	6.261	0.8349	0.4313
Soya_Ham	Soya_Dec	26.14**	6.839	32.98**	6.389	0.0590	0.0818

* indicates significant at a 5% significance level while ** indicates significant at a 1% significance level.

Tests for the LOP from the bivariate Johansen tests are also reported in Table 3. All, but one test, do not reject the *LOP* hypothesis at a 5% level, while one test barely rejects the null hypothesis at a 5% level as the *p*-value is 0.466. Somewhat surprising, this is the test in the relationship between the two fishmeal prices. This might suggest that the different regional

markets for fishmeal may be less integrated than the markets for the better storable commodity soyameal. However, the evidence against the LOP is not strong, but it is worthwhile to note that this is then most likely the relationship the causes the possible deviations against the LOP in the multivariate test.

We can conclude that the cointegration tests indicate that the four prices follow the same stochastic trend. Accordingly, fishmeal and soyameal compete in the same market. Moreover, the LOP seems to hold, or at least is very close to hold as the evidence against it is not very strong. This implies that long-term relationships between these prices, the relative prices, is constant, and therefore also that the generalized composite commodity theorem holds. These results suggest that fishmeal and soyameal are strong substitutes. It is therefore the total demand for fish and soyameal, possibly together with the demand for other oilmeals that determines the price of these oilmeals. To influence the price of fishmeal with this market structure, the changes in demand or supply must be large enough to affect demand and supply for fish- and soyameal combined. This is important, since with this market structure, it is unlikely that increased demand for fishmeal from the aquaculture sector will lead to increased prices for fishmeal, since it has only a negligible share of this market. Hence, with this market structure, increased demand for fishmeal from the aquaculture sector will not increase fishing pressure in industrial fisheries.

4. Concluding remarks

Increased demand for fishmeal from a growing aquaculture sector has the potential to increase fishing pressure in industrial fisheries. However, if this is to be the case, the fisheries must be poorly managed or not managed at all, and there can be no close substitutes to fishmeal. The most important fish stocks in reductional fisheries can today be described as regulated open

access. If this management is efficient, increased demand from aquaculture cannot be a threat to the fish stocks. However, there are many indications that quotas are set higher then biological recommendations and that quotas might be overfished. Hence, the true situation might not be too far from open access. If this is the case, increased demand for fishmeal may well increase fishing pressure.

However, poor fisheries management is not sufficient to cause increased demand for fishmeal to lead to increased fishing pressure. It must also be the case that there are no close substitutes to fishmeal. Our analysis indicates that fishmeal is part of the large oilmeal market, and in particular, that it is a close substitute to soyameal. Hence, it is total supply and demand for oilmeals, of which fishmeal makes up only 4%, which determines prices for fishmeal. With this market structure, increased demand for fishmeal from aquaculture cannot have any effect on fishmeal prices, and accordingly not lead to increased fishing pressure.

Our results indicate that increased demand for fishmeal cannot have led to increased fishing pressure in industrial fisheries because of the market structure for fishmeal. However, demand for fishmeal from aquaculture has grown from basically nothing to 17% of total production in only twenty years time. If demand for fishmeal from the aquaculture sector continues to grow it is possible that the market structure may change. However, this does not have to be the case, since it is not clear that even the demand for fishmeal from the aquaculture sector is mainly because of the unique characteristics of fishmeal. What is clear though is that the current market structure prevents increased demand for fishmeal to have a negative impact on industrial fish stocks. Moreover, the only measure that can ensure that demand for fishmeal does not have a negative impact on these fish stocks due to increased fishing pressure at any time in the future is good fisheries management.

References

Anderson, J. L. (1986) "Private Aquaculture and Commercial Fisheries: The Bioeconomics of Salmon Ranching", *Journal of Environmental Economics and Management,* 12, 353-370.

Anderson, J. L., and J. E. Wilen (1986) "Implications of Private Salmon Aquaculture on Prices, Production, and Management of Salmon Resources", *American Journal of Agricultural Economics,* 68, 867-879.

Anderson, L. G. (1986) *The Economics of Fisheries Management*, John Hopkins Univ. Press, Baltimore.

Asche, F., H. Bremnes, and C. R. Wessells (1999) "Product Aggregation, Market Integration and Relationships Between Prices: An Application to World Salmon Markets", *American Journal of Agricultural Economics,* 81, 568-581.

Asche, F., A. G. Guttormsen, and R. Tveterås (1999) "Environmental Problems, Productivity and Innovations in Norwegian Salmon Aquaculture", *Aquacultural Economics and Management,* 3, 19-30.

Asche, F., K. G. Salvanes, and F. Steen (1997) "Market Delineation and Demand Structure", *American Journal of Agricultural Economics,* 79, 139-150.

Asche, F., and T. Sebulonsen (1998) "Salmon Prices in France and the UK: Does Origin or Market Place Matter?", *Aquaculture Economics and Management,* 2, 21-30.

Bjørndal, T. (1987) "Production Economics and Stock Size in a North Atlantic Fishery", *Scandinavian Journal of Economics,* 89, 145-164.

Bjørndal, T. (1988) "The Optimal Management of North Sea Herring", *Journal of Environmental Economics and Management,* 15, 9-29.

Chung, Y. and Lai, K. 1993. Finite Sample Sizes of Johansen's Likelihood Ratio Tests for Cointegration. *Oxford Bulletin of Economics and Statistics*, 55:313-328.

Clark, C. W. (1973) "Profit Maximization and the Extinction of Animal Species", *Journal of Political Economiy,* 81, 950-961.

Clements, M. P., and D. F. Hendry (1995) *Economic Forecasting*, Cambridge University Press, Cambridge.

Cournot, A. A. (1971) *Researches into the Mathematical Principles of the Theory of Wealth*, A. M. Kelly, New York.

Engle, R. F., and C. W. J. Granger (1987) "Co-integration and Error Correction: Representation, Estimation and Testing", *Econometrica,* 55, 251-276.

FEO. Statistical Information. Fishmeal Exporters' Organisation. Paris.

Gjerde, Ø. (1989) "A Simple Risk-Reducing Cross-Hedging Strategy: Using Soybean Oil Futures with Fish Oil Sales", Review of Futures Markets, 8, 180-195

Goodwin, B. K., T. J. Grennes, and M. K. Wohlgenant (1990) "A Revised Test of the Law of One Price Using Rational Price Expectations", *American Journal of Agricultural Economics,* 72, 682-693.

Gordon, D. V., and R. Hannesson (1996) "On Prices of Fresh and Frozen Cod", *Marine Resource Economics,* 11, 223-238.

Gordon, D. V., K. G. Salvanes, and F. Atkins (1993) "A Fish Is a Fish Is a Fish: Testing for Market Linkage on the Paris Fish Market", *Marine Resource Economics,* 8, 331-343.

Grainger, R. J. R. and Garcia, S. M. 1996. Chronicles of Marine Fishery Landings (1950-1994): Trend Analysis and Fisheries Potential. *FAO Fisheries Technical Paper* No. 359. Rome.

Grafton, R. Q., L. K. Sandal, and S. I. Steinshamn (2000) "How to Improve the Management of Renewable Resources", *American Journal of Agricultural Economics* 82, 570-580.

Hannesson, R. (1993) *Bioeconomic Analysis of Fisheries*, Blackwell, Oxford.

Hempel, E. 1999. Fishmeal: Not as gloomy as it looks. *Seafood International*, April 99:79-82.

Hendry, D. F. (1995) *Dynamic Econometrics*, Oxford University Press, Oxford.

Homans, F. R., and J. E. Wilen (1997) "A Model of Regulated Open Access Resource Use", *Journal of Environmental Economics and Management,* 32, 1-21.

Johansen, S. (1988) "Statistical Analysis of Cointegration Vectors", *Journal of Economic Dynamics and Control,* 12, 231-254.

Johansen, S., and K. Juselius (1990) "Maximum Likelihood Estimation and Inference on Cointegration - with Applications to the Demand for Money", *Oxford Bulletin of Economics and Statistics,* 52, 169-210.

Johansen, S., and K. Juselius (1992) "Testing Structural Hypothesis in a Multivariate Cointegration Analysis of the PPP and the UIP for UK", *Journal of Econometrics,* 53, 211-244.

Lewbel, A. (1996) "Aggregation without Separability: A Generalized Composite Commodity Theorem", *American Economic Review,* 86, 524-561.

Munro, G. R., and A. D. Scott (1985). The Economics of Fisheries Management. *In* "Handbook of Natural Resource and Energy Economics" (A. V. Kneese and J. L. Sweeny, eds.), Vol. II. North Holland, Amsterdam.

Naylor, R. L., R. J. Goldburg, H. Mooney, M. Beveridge, J. Clay, C. Folke, N. Kautsky, J. Lubchenco, J. Primavera, and M. Williams (1988) "Nature's Subsidies to Shrimp and Salmon Farming", *Science,* 282, 883-884.

OW. The Weakly Forecasting and Information Service for Oilseeds, Oils, Fats and Oil meals. Oil World ISTA Mielke Gmbh. Hamburg.

Peña-Torres, J. (1997) "The Political Economy of Fishing Regulation: The Case of Chile", *Marine Resource Economics,* 12, 253-280.

Pike, I. 1996. What Raw Materials Will Be Available in the Future - Fishmeal and Oil. Paper presented at Aquavision 1996. Seattle.

Ravallion, M. (1986) "Testing Market Integration", *American Journal of Agricultural Economics,* 68, 102-109.

Stigler, G. J., and R. A. Sherwin (1985) "The Extent of a Market", *Journal of Law and Economics,* 28, 555-585.

Sutton, J. (1991) *Sunk Costs and Market Structure*, MIT Press, Cambridge, MA.

Vukina, T. and Anderson, J. L. 1993. "A State-Space Forecasting Approach to Optimal Intertemporal Cross-Hedging", ", *American Journal of Agricultural Economics*, 75, 416-424.

Winters, L. A. (1984) "Separability and the Specification of Foreign Trade Fluctuations", *Journal of International Economics,* 17, 239-263.

Footnotes

[1] Traditional or extensive aquaculture differs from intensive or industrial aquaculture in scale and production technology. In particular, in extensive aquaculture the fish is not fed, but consumes whatever nature provides at the location.

[2] Several of these potential negative externalities will also be internalized by the farmers, as they also affect their productivity (Asche, Guttormsen and Tveterås, 1999).

[3] Other regulations that can be used in regulated open access fisheries include input controls and taxes.

[4] A small part is also used for human consumption.

[5] Pelagic fish are free migrating fish species that inhabit the surface waters, as opposed to demersal fish that inhabits the sea floor.

[6] Good representations of this model can be found a number of places, e.g. Anderson (1986), Hannesson, (1993) or Munro and Scott (1985).

[7] It may be worthwhile to note that also Individual Transferable Quota (ITQ) schemes can be regarded as restricted open access. The main difference between ITQ's and other restricted access schemes is that the fishermen's incentives are changed from maximizing their share of the catch to maximize profits for their share of the catch.

[8] Note howewer that this assumption is not reasonable for all fisheries, see e.g. Grafton, Sandal and Steinshmn (2000).

[9] See e.g. Bjørndal (1987; 1998) for a discussion of such fisheries.

[10] However, when dynamics and a positive discount rate is introduced, one can show that for stocks with very low growth rates it may be economically optimal to drive the stocks to very low levels or extinction (Clark, 1973).

[11] For a discussion of fisheries management in Chile, see Peña-Torres (1997).

[12] It might be of interest to note that the open access equilibrium is also the equilibrium with the highest level of effort. Hence, if one is to maximize e.g. employment in a fishery, one is likely to end up very close to the open access equilibrium. Other objectives than rent maximization can therefore lead to substantially higher quotas and lower biomass. Moreover, regional policy and employment are often important parts of fisheries policy, and therefore management.

[13] Indications that these markets are integrated can be found in Vukina and Anderson (1993) and Gjerde (1989), who use soya futures to hedge fishmeal prices.

[14] This is what has given rise to the so-called Armington bias when estimating import demand, when one cannot account for domestic use of domestic production (Winters, 1984). When analyzing a global market rather then import demand to a single country, this problem becomes even more severe.

[15] It is of interest to note that in the papers considering aquaculture even as late as the mid 1980s, extensive farming technologies like ranching seems to have been regarded as more realistic than intensive aquaculture, see e.g. Anderson (1985) and Anderson and Wilen (1985).

[16] In most analysis it is assumed that transportation costs and quality differences can be treated as constant. However, this can certainly be challenged, see e.g. Goodwin, Grennes and Wohlgenant (1990), since if e.g. transportation costs are not constant, this can cause rejections of the Law of One Price.

[17] One can also show that if $\beta < 0$, this implies a complementary relationship between the two goods.

[18] Asche, Bremnes and Wessells (1999) is a recent example of this approach.

[19] The critical values for these tests are nonstandard, and are tabulated in Johansen and Juselius (1990).

[20] A likelihood ratio test for whether a trend should be allowed in the short-run dynamics is distributed as $\chi^2(1)$ with a critical value of 3.84 at a 5% level. With a test statistic of 0.02 we cannot reject the null hypothesis that the trend should be excluded.

[21] For the system the LM test against autocorrelation up the 12th order is distributed as F(112,622), and gives a test statistic of 1.02 with a *p*-value of 0.445.