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# On the Relationship Between Aquaculture and Reduction Fisheries

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*Recently, there has been a growing concern that increased aquaculture production poses an environmental threat to the species targeted in so-called reduction fisheries, the main source for fishmeal. The argument is that increased aquaculture production leads to higher feed demand, and then presumably to higher fishing effort in these fisheries. In this paper we address whether aquaculture production threatens sustainability of such fisheries. First, we ask under which management regimes can 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 part of the larger market for protein meals which includes Soyameal? This is an important issue since the market structure for fishmeal is a key factor in determining whether increased aquaculture production can affect fishmeal prices, and thereby increase fishing pressure in reduction fisheries.*

## 1. Introduction

During the last two decades global aquaculture production has increased substantially because of new and intensive farming techniques.[2] These developments have increased productivity of new high-valued species like shrimps and salmon, on the one hand, and traditional aquaculture species like carp, on the other. The intensification of aquaculture production has, however, led to both local and global environmental concerns. The most important local concerns include discharges from farming sites, destruction of local habitat, and spreading of pathogens (Naylor *et al.*, 2000). The limited geographical extent of the local issues implies that they can, at least in principle, be solved by local regulation (Asche, Guttormsen and Tveterås, 1999).[3] The global concern is that growing aquaculture production will increase fishing pressure on wild-caught species that are subsequently processed into fishmeal, and consequently threaten the sustainability of these reduction fisheries (*i.e.*, the fisheries targeted

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[2] 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.

[3] Several of these potential negative externalities will be internalised by the farmers, as they also affect their productivity (Asche, Guttormsen and Tveterås, 1999; Tveterås, 2002).

for fishmeal and fish oil production). This problem, often labelled the 'fishmeal trap', occurs since marine proteins are important ingredients in the diet for cultured seafood (Naylor *et al.*, 2000). This is an interesting observation, since it implies that the aquaculture industry creates environmental problems via its input market. As the market for fishmeal is global this is then a global problem. Limited availability of marine protein subsequently represents a biological constraint for the growth of intensive aquaculture production.

In this paper we investigate to what extent the 'fishmeal trap' associated with aquaculture growth represents an environmental problem. We decompose the question into two key issues, one pertaining to the regulation of capture fisheries and one pertaining to the market for protein meals. If increasing demand for fishmeal increases fishing effort, growth of aquaculture production can lead to unsustainable capture fisheries. However, this requires that aquaculture depends on fishmeal in fish feed, so that aquaculture growth actually increases total demand for fishmeal.

We begin by discussing how increased demand affects a fish stock under different management regimes in a bio-economic model. There are a number of management forms in the world's fisheries. These generally fall into three main groups: open access, optimal management (or sole-ownership), and restricted open access. We investigate the effect of increased demand for wild fish with these three benchmark groups, and show that the effect critically depends on the management system. We then relate this to the actual management situation for the reduction fisheries.

The next step is to consider the market for protein meals because the extent to which increasing aquaculture production increases fishing pressure also depends on whether there are close substitutes for fishmeal. In particular, if there are close substitutes for fishmeal, the effect on the fishmeal price because of increased demand from aquaculture will be limited, and accordingly give little incentive to increase fishing pressure. Most of the world's fishmeal has traditionally been used as a protein source in livestock feeds, primarily pig and poultry.[4] This suggests that fishmeal is a part of the much larger protein meal market. In aquaculture proteins of a marine origin are often regarded as superior. However, as in livestock feeds, there are alternative protein sources. Most cultured marine and freshwater species can use at least some vegetable meals such as soyameal in their diet, and quite a few cultured species like carp and tilapia are herbivore in nature. Fishmeal is, nevertheless, increasingly used in compound aquaculture feeds to increase growth, for carnivore, omnivore, and also herbivore species. It is therefore of substantial interest whether fishmeal is a unique product or a part of the larger market for protein meals, including that of soyameal. This is important because the market structure is instrumental in determining how increased demand for feed from aquaculture can affect the price for fishmeal.

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

## 2. Increased Demand and Fisheries Management

This section first gives a brief overview of the world's industrial fisheries. We then turn to a simple bio-economic model to illustrate the importance of management regime when demand increases, finally discussing 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 of 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 destined for fishmeal production amounted to approximately 30 million MT (metric tons) in the 1990s, yielding an average of 6-7 million MT fishmeal. The main reduction fishery nations in 1997 are shown in Figure 1 with their respective share of global fishmeal production.

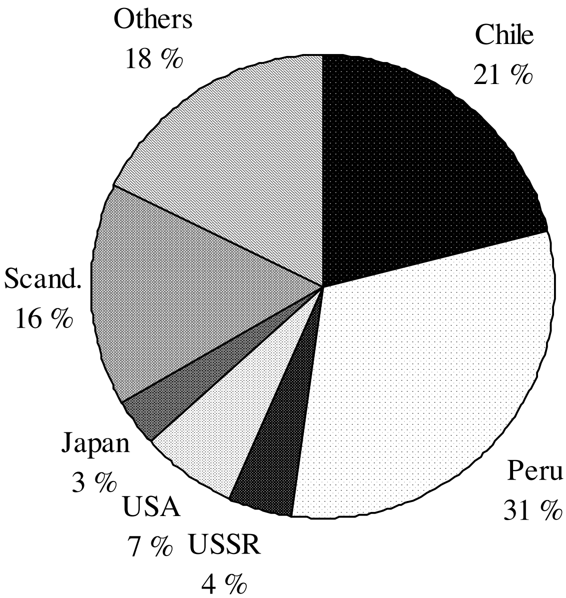
Based on their rich fisheries of Peruvian anchoveta, Chilean jack mackerel, and South American pilchard, Chile and Peru alone account for over 50% of global fishmeal production. Other substantial producers are the Nordic countries, Denmark, Iceland, and Norway. Combined, their fisheries provide raw material for approximately 15% of global fishmeal production.

A characteristic of the pelagic fisheries is that while the quantity going directly to human consumption stays relatively stable, the "surplus" that goes to reduction can vary substantially (Hempel, 1999). Thus, in years when the catches are low, such as *El Niño* periods, the fishmeal industry is depressed. Most of the pelagic fisheries have also been described as fully exploited or over-exploited by the FAO (UN Food and Agricultural Organization, Grainger and Garcia, 1996). A significant expansion of the global fishmeal production, beyond the 6-7 million MT that is normally produced, is therefore not likely unless prices for fishmeal increase substantially.[6]

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

[6] In the short term, greater yields could be taken if prices increased, although these would be unsustainable and lead to lower long-term sustainable yields, as illustrated in Section 2.2.

Figure 1: World Fishmeal Production in 1997
(Fishmeal Exporters Organisation)




*2.2 A simple bio-economic model*

Let us then turn to the effect of increased demand in a fishery. We use the static Gordon-Schaefer model, since introducing dynamics do not add essentially to our discussion of why increased demand for a species might pose a threat to fish stocks.[7] Textbook versions of this model cover the two most common institutional regimes in the fisheries economics literature, open access and optimal management (Homans and Wilen, 1997).[8] In an open access fishery there is no management and the fish stock represents a common pool resource. If the fishery is optimally regulated in this model, a setting that is often represented as a fishery regulated by a sole-owner, the discount rate is assumed to be zero. In addition to these two institutional regimes we also consider a regulated open access setting, since this is the most commonly observed management structure in the world's fisheries. A Total Allowable Catch (TAC) is used as an example of a regulated open access fishery, but alternative regulations like input factor restrictions or taxes can be used in place of or in combination with, a TAC. In a regulated open access regime one or more inputs or outputs are restricted, so that the fishery is generally regarded as biologically safe. However, one pays little attention to the economic incentives in the

[7] Accounting for dynamics will not change the open access equilibrium, but will shift the maximum economic yield equilibrium to account for the effect of the discount rate that is not included in the static model.

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

fishery, as one typically observes over-capacity and rent dissipation. This is what is known as a Class II common property problem in fisheries management (Munro and Scott, 1985). 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. Such assumptions should be unproblematic since the size of the quota tends to be dominated by biological rather than economic considerations.[9]

The net natural growth in the biomass is

$$F(x) = rx(1 - x / k) \tag{1}$$

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 equation (1) with a price $p$, giving the sustainable revenue curve, $TR$. We will here, as in most analyses, assume that the price is given from a world market. This is reasonable for species that are used for fishmeal production, since the value of the end product does not vary much with varieties of pelagic species used.

Harvest $H$ is given as

$$H = \gamma x^{\alpha} E \tag{2}$$

where $y$ is a catchability coefficient, $a$ gives the strength of the stock effect and $E$ is fishing effort. The fishery is in equilibrium when growth of fish stock equals harvest, $F(x) = H$.

Fishing cost is

$$C = cE = cH / \gamma x^{\alpha} \tag{3}$$

where $c$ is the unit cost of fishing effort.

Total profits or rent are

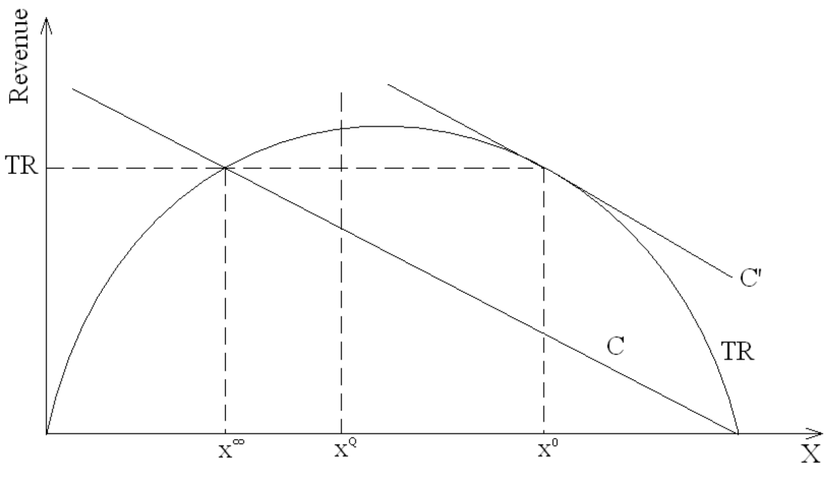
$$\Pi = pH - cE \tag{4}$$

This model has two equilibria: Under open access all rents are dissipated as in all competitive industries and the equilibrium condition is accordingly that price equals average cost, giving a biomass at the level $x^{\infty}$. Under optimal management, the harvest is set by maximizing equation (4), giving the equilibrium condition that price should equal marginal cost, leading to a

9 It may be worthwhile to note that Individual Transferable Quota (ITQ) schemes can also 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 maximising their share of the catch to maximise profits for their share of the catch.

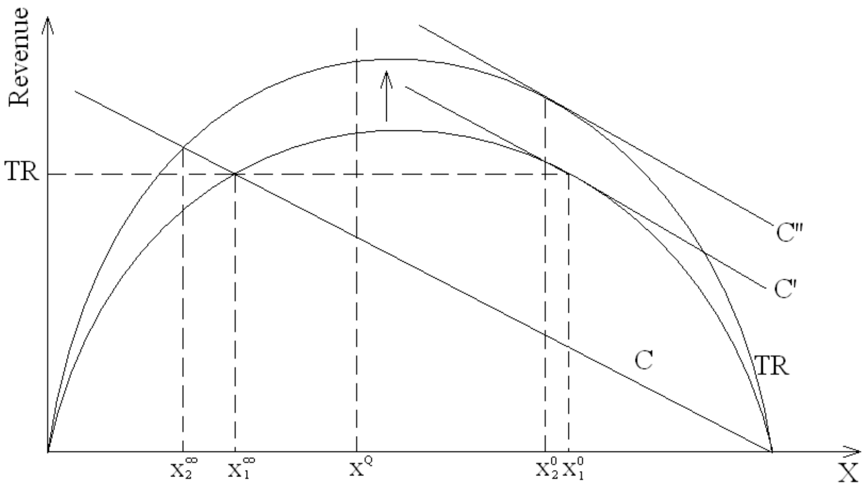
biomass at the level $x^0$. In contrast to the standard competitive case, rents will be generated because of the biological production process. This is graphed in Figure 2, where the sustainable revenue curve, *TR*, is shown together with the cost curve, *C*. The cost curve is drawn in a linear fashion (*i.e.* assuming $\alpha = 1$), although in general it will be non-linear and monotonically increasing. The qualitative implications are therefore not affected by this linearity, but the distance between the optimal and the open access equilibrium will differ. 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.* $E^\infty > E^0$. Note that since the harvested quantity is a function of the net growth of the fish stock, this gives a backward bending supply schedule since if a small stock is reduced, net growth is also reduced. Under regulated open access, a quota *Q* determines total harvest. The quota is typically determined 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. In Figure 2 an arbitrarily set quota is inserted at the level, $x^Q$.

Figure 2: Solutions for Three Different Regulatory Regimes




Assume then that the price increases due to increased demand in the world market. The higher price increases the value of the natural growth of the fish stock and the harvest, as introduced in Figure 3 with the new sustainable revenue schedule, *TR'*. When the fishery is in open access and when it is optimally managed, the increased value of the fish will increase the effort in the fishery and decrease the biomass. Under open access, one will normally operate at biomass levels lower than *k*/2, the biomass associated with Maximum Sustainable Yield (MSY), which traditionally has been the management criterion advocated by biologists. This puts the supply on the backward bending part of the supply schedule. A higher price will then lower landings 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 $\alpha$ parameter close to zero) can be driven down to very low levels.[10] This is important here, since many of the stocks targeted in reduction fisheries are pelagic.

Figure 3: Effects of a Price Increase on Fishing Pressure




In the case with optimal management, the size of the landings responds to the increased prices. The biomass will, however, always be higher than *k*/2, the level associated with Maximum Sustainable Yield (MSY). One can therefore hardly argue that the fishery poses a threat to the stock under optimal management.[11] If the fishery is regulated by a quota that is set without paying attention to economic factors, the quota remains the same when demand changes, the biomass remains the same, but the value of the catch increases. The obvious conclusion is that if the fishery is not allowed to respond to economic incentives the increased demand for reduction species will not have much effect, other than perhaps depressing season length.[12]

[10] See e.g. Bjørndal (1987; 1988) for a discussion of such fisheries. The model as represented cannot handle cases where the stock effect is zero, as harvesting cost then will be independent of stock size. However, it is unlikely that the stock effect will be zero in any relevant case, as there will always be some search costs.

[11] 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). Some of the big whales seem to be the only candidates for species that it might be economically optimal to drive to extinction, but even for them this is doubtful. Hence, this is not a very relevant scenario.

[12] See Homans and Wilen (1997) on effects of regulated open access fisheries using season length as the management tool.

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 as long as there are costs associated with the harvesting process. It is clear, however, that with very low stock levels the species also becomes substantially more vulnerable to changes in other factors like water temperature, salinity, *etc*. that are not accounted for in a bio-economic model. In more general biological models, one may also increase the probability of extinction.

### *2.3 The management of industrial fisheries*

The analysis above indicates that increased demand for any species is mainly a problem if the fishery is not managed, *i.e.* is operated as an open access fishery. What then are the management regimes for the most important pelagic stocks used in industrial fisheries? As noted above, most of the world's reduction fisheries are carried out in relatively few countries, with Peru and Chile as the most important (see Figure 1). The stocks of Peruvian anchoveta and Chilean jack mackerel have shown their vulnerability both to the weather phenomenon *El Niño* and poor fisheries management. Fisheries management has improved over the last decade though, with increasingly stricter regulations on inputs.[13] The most important tools used in Chile and Peru today are TACs, limited access, 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 other additional restrictions. Nevertheless, 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 pre-collapse levels. In the US, the Menhaden fishery is the main industrial fishery, and is also regulated with a TAC.

A first glance indicates that the most important pelagic fisheries are regulated so that over-fishing is prevented, and accordingly open access is not a correct description of these fisheries. However, quotas tend to be high and one may often question whether the state of the fish stocks is the main priority when the quotas are set. Hence, it is not clear that the situation is very different from what it would prevail 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.[14] Whether increased demand for fishmeal from a growing aquaculture industry is harmful for the fish stocks targeted in industrial fisheries will to a large extent depend on the market structure for fishmeal.

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

[14] 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 maximise *e.g.* employment in a fishery, one is likely to end up very close to the open access equilibrium. Other objectives than rent maximisation 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.

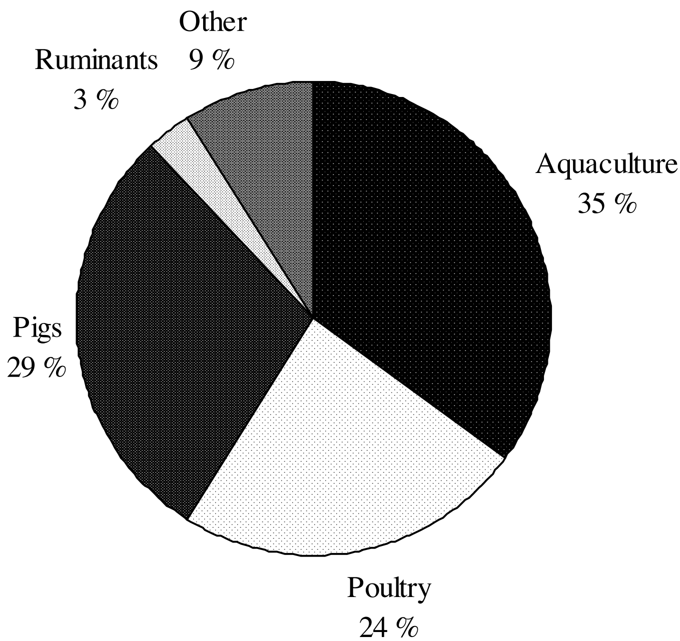
## 3. The market

We now turn to the market for fishmeal. What is the market is an important question since its extent largely determines whether increased demand from aquaculture will affect prices for fishmeal and thus the stock level in poorly managed fisheries. We start with a brief discussion of the world's protein meal markets and then present our data. We go on to outline the methodology we use to delineate the market before we report and discuss the empirical results.

### *3.1 The world's protein meal markets and data*

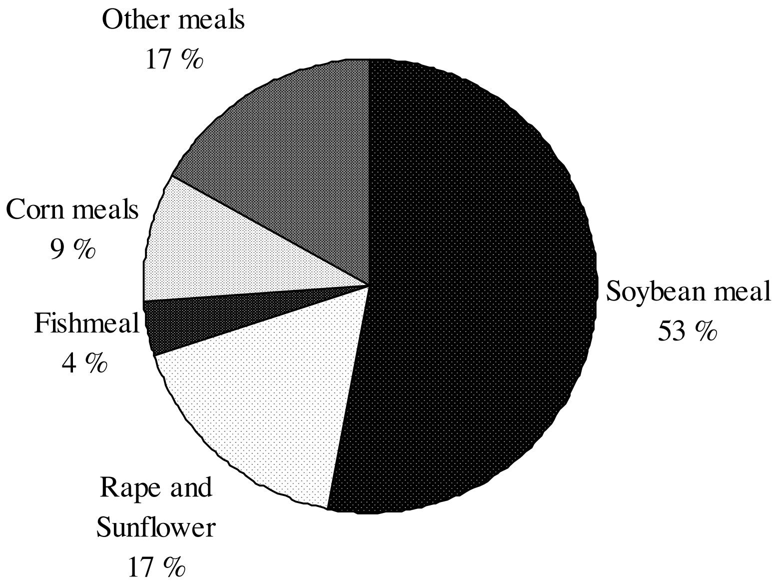
The aquaculture industry is far from the only consumer of fishmeal. In Figure 4, the main sectors that use fishmeal are shown for 2000.

Figure 4: Estimated Total Use of Fishmeal (Pike, 2000)




As one can see pig and poultry production sectors jointly consume 53% of the production against 35% for aquaculture. Aquaculture is, nonetheless, up from 17% in 1996, which represents a rapid expansion in fishmeal consumption. For most of the species that use fishmeal as feed, including aquaculture species, marine proteins are only a part of their diet. Other protein meals, with soyameal as the largest, make up a major share. If one looks at the total market for protein meals in Figure 5, global fishmeal production is minor compared to the total protein meal production.

Figure 5: World Production of Protein Meals 1996/97 (OW, 1999)




There are two main explanations why fishmeal is used in livestock production. One explanation stresses the uniqueness of fishmeal. Fishmeal has a higher protein content than the other protein meals, and also has a different nutritional structure. In particular, this is the case with respect to amino acids that encourage growth and general health of animals. If fishmeal is unique, increased demand from aquaculture production for fishmeal is likely to increase prices, and therefore increase fishing pressure particularly from poorly managed fish stocks. The other explanation emphasises that fishmeal is cheap protein. If fishmeal is primarily demanded because it is cheap protein, one would expect a high degree of substitutability between fishmeal and other protein meals.[15]
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. However, if fishmeal is a close substitute for other protein meals, one would not expect the price of fishmeal to be greatly influenced by increased demand from aquaculture, since the price is determined by total demand for protein meals, of which demand from aquaculture occupies a small share.

To determine fishmeal's position in the protein meal market, we will investigate its relationship to soyameal, since soyameal is the largest of the vegetable

[15] 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.

meals. The most obvious procedure would be to estimate demand equations and evaluate the cross-price elasticities. Although there exist exchanges that give price data of good quality at higher frequencies than annually, it is extremely difficult (if not impossible) to obtain reasonable quantity data, as in most global markets.[16] Analysis of the relationships between prices is an alternative approach, even though it 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.

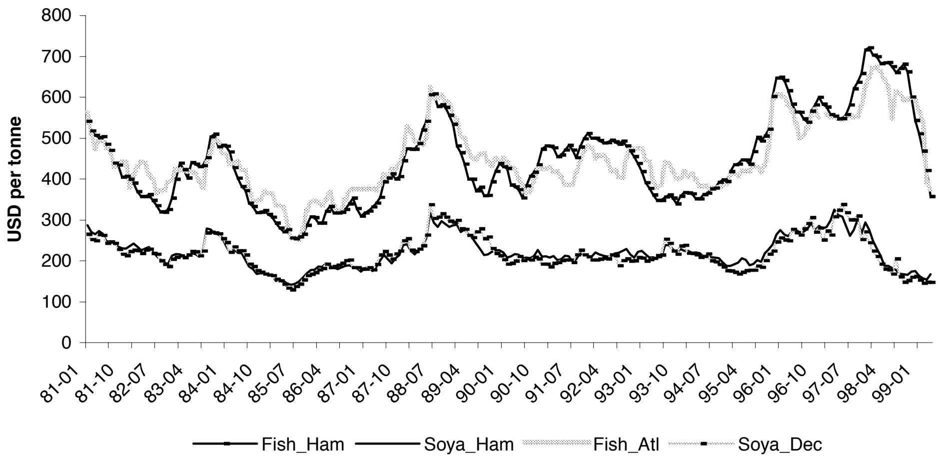
We use fishmeal and soyameal prices reported on a monthly basis from Europe and USA provided by the International Fish Oil and Meal Association, (IFOMA) (1998, 2000), in the period spanning January 1981 to April 1999.[17] The European prices are reported from Hamburg, and are denoted as Fish_Ham and 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 6. Note that the fishmeal prices are substantially higher than the soyameal prices. This is primarily because of the higher protein content. If one adjusts for the protein content, most of the difference disappears. The data period is interesting for at least two reasons: First, 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. Second, the intensive aquaculture industry has experienced a tremendous growth in this period.[18] If fishmeal is primarily demanded due to its special attributes, this should show up as fishmeal and soyameal being different market segments during this period.

[16] This 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 analysing a global market rather than import demand to a single country, this problem becomes even more severe.

[17] The primary data sources are Feedstuff, Minneapolis, Minnesota for US price data, while the European price data originates from Oil World, The Weekly Forecasting and Information for Oilseeds, Oils, Fats and Oilmeals, Hamburg.

[18] 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 (1986).

Figure 6: Monthly Fishmeal and Soybean Meal Prices (IFOMA, 1998, 2000)




Before carrying out a statistical analysis the time series properties of the data were investigated using Dickey-Fuller tests. The lag length was chosen as the highest significant lag. All prices are found to be non-stationary, 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 | Variable in levels | Variable in first differences |
|---|---|---|
| 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) |

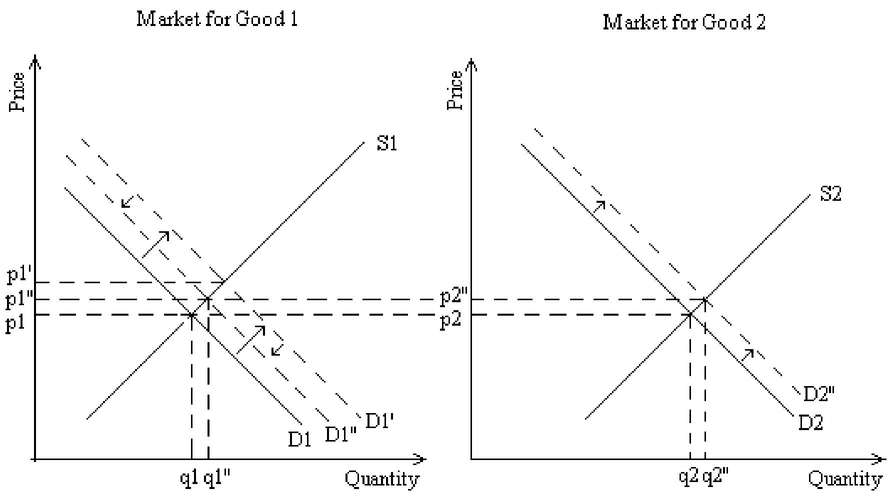
Note: ** indicates significant at a 1% significance level. The number in parenthesis is the number of lags used in ADF test, which is chosen on the basis of the highest significant lag out of 12 lags that were used initially. The tests for variables in levels include a constant and a trend, while in 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 the difference in value, from one market to the other, represents no more than the cost of transportation” (Cournot, 1971). While his definition of a market relates to geographical space, similar definitions are used for product space, where quality differences play the role of transport costs (Stigler and Sherwin, 1985; Sutton, 1991). The main arguments for why prices equalise within a market are either arbitrage or substitution.

To provide the intuition behind price founded definitions of a market, we have sketched two market equilibria in Figure 7, where the prices are normalised to be identical initially.

Figure 7: The Effects of a Positive Shift in the Demand for Good 1




Assume then that there is a demand shock in market 1 that shifts the demand schedule to D1'. The price and quantity is then increased. What happens in market 2 depends on the degree of substitution for the consumers. If there is no substitution the price and quantity is not affected. If the goods are substitutes the demand schedule in market 2 is shifted outwards, and this will induce a spillover effect back to market 1 so that the demand schedule is shifted back from D1'. If the goods are imperfect substitutes, the relative prices will change. If the goods are perfect substitutes the spillover effect will leave demand for Good 1 at D1" and the demand for Good 2 at D2'' so that the relative price between the two markets (goods) are equal again at p1''= p2''. This is often known as the Law of One Price (LOP). The strength of the influence of the shock in market 1 on market 2 is normally measured by cross price elasticities (which depend on both price and quantity). However, one can also look at the effect of the demand shock only from the price space. When the demand curve in market 1 shifts, the price changes. This can then have three types of effect for the price of the other good. If there is no substitution effect, the demand schedule does not shift and there is no movement in the price. If there is a substitution effect, the demand schedule for Good 2 shifts up, and the price shifts in the same direction as the price of the first product did. At most, the price of the other product can shift by the same percentage as the price of the first product, making the relative price constant so that the Law of One Price (LOP) holds.[19]

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

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

where $\alpha$ is a constant term (the log of a proportionality coefficient) that captures transportation costs and quality differences and $\beta$ gives the relationship between the prices.[20] If $\beta = 0$, there is no relationship between the prices and therefore no substitution, 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 $\beta$ is greater than zero, but not equal to one, there is a relationship between the prices, although the relative price is not constant, and the goods will be imperfect substitutes.[21]

Equation (5) describes the situation when prices adjust immediately. There is, however, often a dynamic adjustment pattern; the dynamics can be accounted for by introducing lags of the two prices (Ravallion, 1986). It should be noted here that even when dynamics are introduced, the long-run relationship has 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 generalised commodity theorem of Lewbel (1996).

Since the late 1980s, one has become aware that when prices are non-stationary, 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 does not allow testing of the LOP hypothesis, while this is easily done using the Johansen test.[22] Since our price series seems to be non-stationary, we will use this approach.

[19] For completeness one should also mention that if the demand schedule in market 2 shifts downwards, the two goods are complements.

[20] 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.

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

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

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

$$\mathbf{x}_t = \mathbf{\Pi}_1 \mathbf{x}_{t-1} + \ldots + \mathbf{\Pi}_k \mathbf{x}_{t-k} + \boldsymbol{\mu} + \mathbf{e}_t \tag{6}$$

where each of the $\mathbf{\Pi}_i$ is a ($N$×$N$) matrix of parameters, $\mu$ a constant term and $\mathbf{e}_t \sim iid(0, \mathbf{\Omega})$. The VAR system of equations in (6) written in error correction form (ECM) is;

$$\Delta \mathbf{x}_t = \sum_{i=1}^{k-1} \mathbf{\Gamma}_i \Delta \mathbf{x}_{t-i} + \mathbf{\Pi}_k \mathbf{x}_{t-k} + \mathbf{\Phi} \mathbf{D}_t + \boldsymbol{\mu} + \mathbf{e}_t \tag{7}$$

with

$$\mathbf{\Gamma}_i = -\mathbf{I} + \mathbf{\Pi}_1 + \ldots + \mathbf{\Pi}_i, i = 1, \ldots, k - 1$$

and

$$\mathbf{\Pi}_K = -\mathbf{I} + \mathbf{\Pi}_1 + \ldots + \mathbf{\Pi}_K$$

Hence, $\mathbf{\Pi}_K$ is the long-run 'level solution' to (6). If $\mathbf{x}_t$ 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); $\mathbf{\Pi}_K \mathbf{x}_{t-k}$ ~I(0). Hence, either $\mathbf{x}_t$ contains a number of cointegration vectors, or $\mathbf{\Pi}_K$ must be a matrix of zeros. The rank of $\mathbf{\Pi}_K$, $r$, determines how many linear combinations of $\mathbf{x}_t$ are stationary. If $r = N$, the variables in levels are stationary; if $r = 0$ so that $\mathbf{\Pi}_K = 0$, none of the linear combinations are stationary. When $0 < r < N$, there exist $r$ cointegration vectors, or $r$ stationary linear combinations of $\mathbf{x}_t$. In this case one can factorize $\mathbf{\Pi}_K$; $\mathbf{\Pi}_K = \boldsymbol{\alpha\beta}'$, where both $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are ($N$×$r$) matrices, and $\boldsymbol{\beta}$ contains the cointegration vectors (the error correcting mechanism in the system) and $\boldsymbol{\alpha}$ 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).[23]

The Johansen procedure allows hypothesis testing on the coefficients $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$, using likelihood ratio tests (Johansen and Juselius, 1990). In our case, it is restrictions on the parameters in the cointegration vectors $\boldsymbol{\beta}$ that is of most interest. More specifically, in the bivariate case there are two price series in the

[23] The critical values for these tests are non-standard, and are tabulated in Johansen and Juselius (1990).

$\mathbf{x}_t$ vector. Provided that the price series are cointegrated, the rank of $\mathbf{\Pi} = \boldsymbol{\alpha}\boldsymbol{\beta}'$ is equal to 1 and $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are 2×1 vectors. Of particular interest is the Law of One Price (LOP), which can be tested by imposing the restriction $\boldsymbol{\beta}' = (1,-1)'$. 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 normalisation is imposed in the case with four price series, one representation of the matrix of cointegration vectors is:

$$\boldsymbol{\beta} = \begin{bmatrix} 1 & 1 & 1 \\ -\beta_1 & 0 & 0 \\ 0 & -\beta_2 & 0 \\ 0 & 0 & -\beta_3 \end{bmatrix} \tag{8}$$

That is, one can represent the system with $n$ prices with $n-1$ pairwise relationships. If all $\boldsymbol{\beta}$ 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 to what Hendry (1995, p. 313) labels the "curse of dimensionality" in dynamic models, since with a limited number of observations and thereby limited degrees of freedom one has 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, possibly conflicting, estimates of the same long-run relationships. We will therefore estimate both a multivariate system and bivariate systems.[24]

### *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.[25] An LM-test against autocorrelation up to the 12$^{th}$ order cannot be rejected for

[24] 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).

[25] 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.

the system with four lags.[26] Hence, four lags seem sufficient to include all dynamics. However, we cannot reduce the lag length further without getting problems with dynamic misspecification. The results from the multivariate test are reported in Table 2.

Table 2: Multivariate Johansen Tests of Fishmeal and Soyameal Prices

| $H_o$: | 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.

The trace test indicates 3 cointegration vectors at the 5% level. The max test suggests two cointegration vectors at a 5% significance level, but with three at a 10% significance level. Adopting the rank 3 model, we test for the LOP, which yields a test statistic of $\chi^2(3)=8.33$ that rejects the null of the LOP at the 4% level. Hence while the test rejects at the conventional (5%) level, evidence against the LOP is not compelling.

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 substantially the likelihood 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 a 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 cointegrating vector for all pairs of prices. Hence, these tests also indicate that there is one stochastic trend in the system.

[26] The LM test for autocorrelation up to the 12th order is distributed as F(112,622), and gives a test statistic of 1.02 with a $p$-value of 0.445.

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 (p-values) | Auto-corr-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 0.047. Somewhat surprisingly, this is the test of 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. This result is still somewhat surprising since with the link between fishmeal and soyameal in each of the markets and the link between the soyameal markets, transitivity suggests that the LOP should also hold for the fishmeal markets. However, it is worthwhile noting that this is most likely the relationship that 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 holding) 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 that the generalised 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 protein meals that determines the price of these protein meals. In order for aquaculture 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 such a 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 the protein meal market. It therefore seems unlikely that increased demand for fishmeal from the aquaculture sector will 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 reduction fisheries. It does, however, require that the fisheries are poorly managed (or not managed at all) and that there are no close substitutes for fishmeal. The most important reduction fisheries operating internationally can be described as regulated open access. If this management regime is efficient, increased demand from aquaculture does not pose a threat to the fish stocks. However, there are many indications that quotas are set higher than biological recommendations and that quotas might be over-fished. With such a situation one might not be too far from open access. If so, increased demand for fishmeal may well increase fishing pressure.

Poor fisheries management is not sufficient to cause increased fishing pressure in these circumstances. In addition, there must not be any close substitutes for fishmeal, since close substitutes would alleviate the demand pressure on the market for marine proteins and consequently the fisheries. Our analysis indicates that fishmeal is part of the large protein meal market, and, in particular, that fishmeal is a close substitute to soyameal. With such a market structure it is first and foremost total supply and demand for protein meals; of which fishmeal makes up a mere 4%, that determines prices for fishmeal. One is then led to the conclusion that increased demand for fishmeal from aquaculture cannot have had any significant impact on fishmeal prices.

Our results indicate that increased demand for fishmeal cannot have led to increased fishing pressure in reduction fisheries. Poultry and pig producers, who switch to cheaper vegetable protein sources, counteract aquaculture's increasing demand for marine proteins, leading to a spillover demand from the fishmeal market to the larger vegetable protein markets. This situation can change if aquaculture production continues to grow. Aquaculture's demand for fishmeal has grown from basically nothing to 35% of total production in only twenty years. If this trend continues demand for fishmeal may become more inelastic, leading to higher fishmeal prices. It is unclear, however, how essential fishmeal will be for aquaculture production as new feed technologies reduce the dependencies on marine proteins in aquaculture feeds. What remains clear is that increased fishmeal demand from aquaculture has not negatively impacted the stocks targeted in reduction fisheries so far. Furthermore, the only measure that can ensure that it continues to stay this way is good fisheries management.

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