**NORWEGIAN SCHOOL OF
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Is the Aquaculture Industry Caught In a Fishmeal Trap?

An examination of the fishmeal-soybean meal relationship and research initiatives aimed at reducing the fishmeal inclusion level in fish feeds

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Master Thesis in Economic Analysis (ECO)

Preface

This thesis was written as a part of the master in Economic Analysis (ECO) at the Norwegian School of Economics and Business Administration (NHH).

The motivation behind this paper was an interest to learn more about global meal markets and especially the fishmeal market. Working on the thesis has also made me familiar with the international fishing industry as well as issues regarding the world hunger crisis. The theoretical knowledge obtained at NHH has enabled me to perform both qualitative and quantitative exercises that have helped answer the thesis' hypothesis.

First I would like to thank my guiding professor Rögnvaldur Hannesson. He has helped me pinpoint an interesting approach to the fishmeal market and provided guidance on both the aquaculture industry as well as the thesis build up.

Furthermore I would like to thank Jonas Andersson for invaluable input on the time series methodology used in this thesis. Most of the statistical theory applied in this paper is something I have learned through his inspiring courses at NHH.

I would like to extend gratitude to Audun Lem and Globefish (a subdivision of the United Nations' Food and Agricultural Organization) for providing me with historical price series and input on research initiatives within the aquaculture industry. I am also grateful to Louise Buttle and EWOS for providing me with information on their research program on salmon feed diets.

Writing this thesis has been a challenging process and I feel I have learned a lot about how theoretical knowledge can be used in practical problem solution. This is something I will bring with me to the work life.

Bergen, 10. June 2011 Per Gunnar Nordahl

Abstract

The world hunger crisis is growing larger and increased aquaculture production could be a way to ease the situation. However, carnivorous aquaculture production does currently require fishmeal which only exists at a limited supply and this has led some to believe that the future growth of the aquaculture sector will be restrained – caught in a fishmeal trap. Cointegration analysis on the fishmeal and soybean meal price show that these raw materials have historically been considered as substitutes, but that this relationship has weakened as the aquaculture industry has expanded. Research programs aimed at reducing the fishmeal inclusion rate in fish feed diets have already come a long way, and it is likely that an aquaculture feed pellet containing minimal amounts of fishmeal one day will be possible. The growth of the aquaculture sector will therefore in the short-term be influenced by the availability of fishmeal, but it is not likely that the industry will be locked in a fishmeal trap in the long-run.

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1 Introduction

1.1 A world hungrier than ever

According to the Food and Agricultural Organization of the United Nations, world hunger has by 2009 exceeded 1 billion people: A staggering 1/6 of the world population. "A dangerous mix of the global economic slowdown combined with stubbornly high food prices in many countries has pushed some 100 million more people than last year into chronic hunger and poverty," said FAO Director-General Jacques Diouf in the 2009 edition of The State of Food Insecurity in the world (FAO 2009). "The silent hunger crisis poses a serious risk for world peace and security. We urgently need to forge a broad consensus on the total and rapid eradication of hunger in the world and to take the necessary actions," he continued.

In the 1980's good progress was made on reducing chronic hunger, and throughout the first half of the 1990's it was actually decreasing quite rapidly (see figure 1.1). However, from 1995 through 2009 world hunger increased substantially as a result of high commodity prices and economic turbulence. As the global economy recovers, the number of undernourished people is estimated to go down somewhat, but still remain at an unacceptable high level. The world population is projected to increase to 8 – 12 billion people within 2050 (UN 2007), which makes it highly likely that the crisis will grow even bigger if the current food balance is not improved. To ease the situation, issues that must be addressed are amongst others:

- The inadequate purchasing power in many developing net-food importing countries (Ng and Aksoy 2008)
- Countries in protracting crisis must be given special attention[1] (FAO 2010a)
- Increase the efficiency of food distribution and consumption
- Increasing the long-run global supply of food

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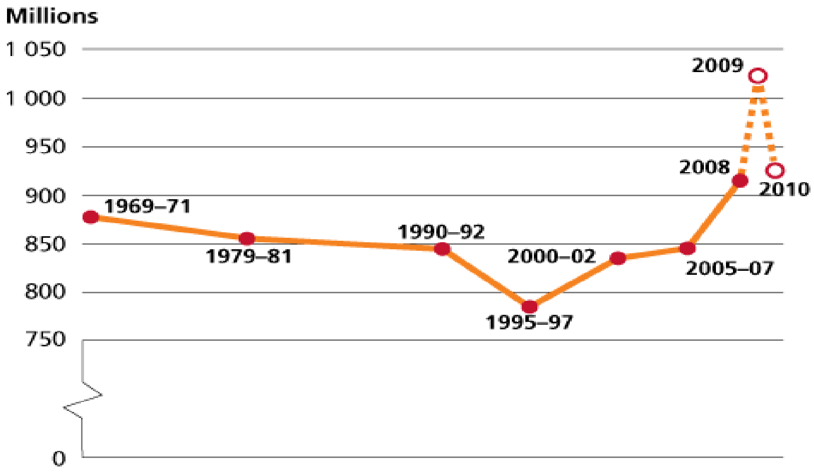
[1] Protracted crisis situations are characterized by recurrent natural disasters and/or conflict, longevity of food crises, breakdown of livelihoods and insufficient institutional capacity to react to the crisis.

This paper will focus on how the long-run food supply can be improved.

Figure 1.1: Trends in world hunger (FAO 2010)



1.2 The search for sustainable sources of protein

Like all animals, the human body needs exogenous supply of nutrients to survive. One of the most essential substances is protein which is obtained by herbivorous animals by consuming large amounts of plant materials and by carnivorous organisms by eating the herbivorous organisms. In 2003, fish accounted for 16 percent of the consumed animal protein worldwide and in some Asian countries the proportion ranges as high as 30 – 50 percent (Rana et al. 2009). This means that about 1 billion people rely on seafood as their main source of proteins and there are several reasons why demand for seafood will probably just increase over time.

First, the world population growth is expected to occur in under-developed regions, including Africa and parts of Asia[2] (UN 2007). These are regions with strong cultural ties to seafood cultivation, capturing and consumption, and it is thus likely that we will see a seafood demand increase in these areas. Secondly, it is expected that most of the population growth will take place in the coastal areas (Abel and McDonnald

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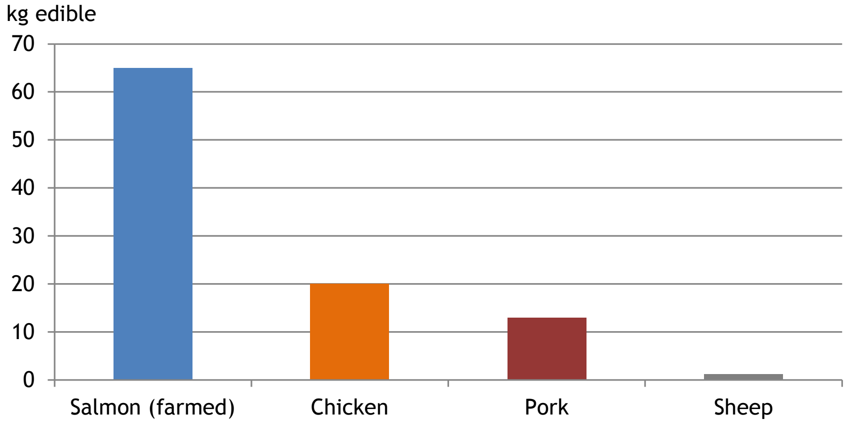
[2] The United Nations (2007) estimate that from 2007 to 2050 the population growth in Africa and in Asia will be at 1 billion and 1.2 billion people respectively. This accounts for 86 percent of the estimated global population increase.

2001), and for the population on average this means lower transportation costs for seafood, thus making it relatively more competitive. Thirdly, not only will Africa and Asia experience fast population growth, but also a high increase in Gross Domestic Product (GDP) per person (IMF 2010). Historically, such an increase in affluence has facilitated shifts in dietary lifestyle, with huge increases in the consumption of meat and milk products accompanied by a decline in grain consumption (Rana et al. 2009).

There are however more fundamental reasons why one might argue that the increased food supply *should* come from the aquaculture sector rather than terrestrial meat production. The first argument has to do with the feed conversion ratio, meaning how much edible substance is obtained for the feed that is put in production. Figure 1.2 shows how much edible meat you will get from 100 kilograms (kg) of feed input in various species. In salmon production you get 65 kg of edible meat from 100 kg of feed, while the number is 20, 13 and 1.2 kg for chicken, pork and sheep respectively (BioMar 2011). The feed conversion numbers for other seafood species are similar to that of salmon, and it illustrates the superior ability that aquaculture production has over terrestrial farmers when it comes to convert feed into edible meat. Thus, aquaculture production is a more efficient way of producing proteins than traditional land-based meat production, and could help ease the global food situation.

Figure 1.2: Edible meat from 100 kg of feed (BioMar 2011)

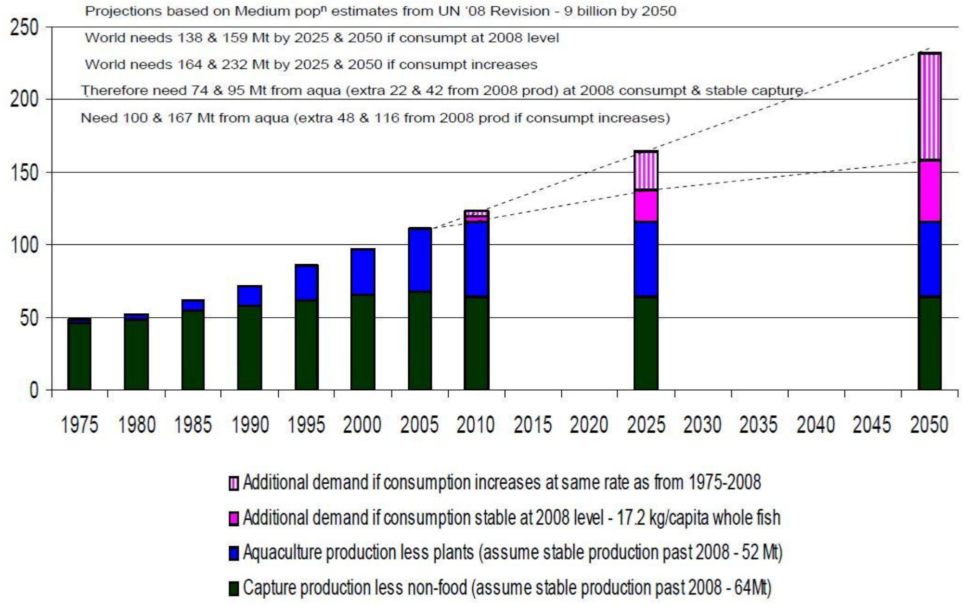


But terrestrial production consumes not only relatively more feed, but also huge amounts of water. E.g. at a temperature of 25 degrees Celsius, cattle will netted for milk production consume about 80 liters of water each day. Livestock's use of water and contribution to water depletion are high and growing (LEAD 2006). According to the World Health Organization about 1.1 billion people have no access to any source of improved drinking water (WHO 2011). Contrary to livestock production, aquaculture production does not consume any water and thus increased aquaculture farming would not put further pressure on an already scarce resource.

1.3 A challenging demand/supply balance

As the population grows over time the demand for seafood will rise. If the population should increase to 9 billion people by 2050 (UN medium population estimate) and the consumption of fish per capita remains at the 2008 level (17.2 kg/person), then the demand for seafood will increase from about 110 million tons in 2005 to 160 million tons in 2050. Should growth in fish consumption per capita persist, then the total demand will reach 230 million tons – an increase of 110 percent.

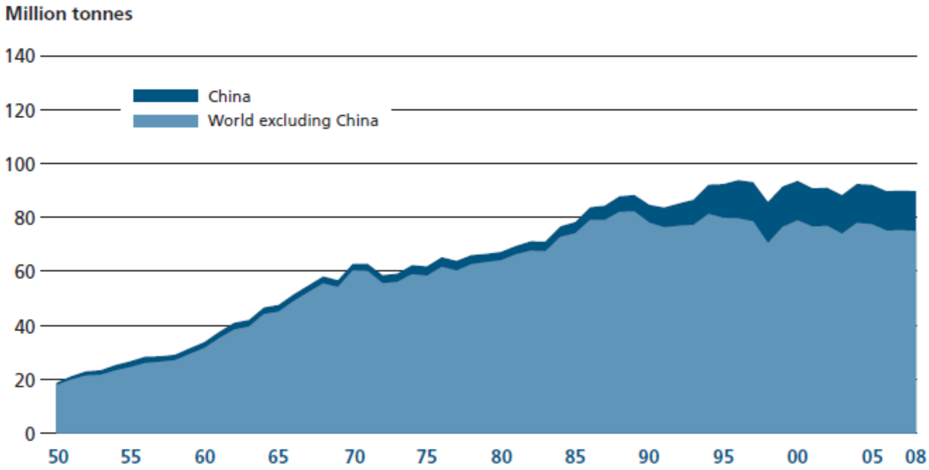
Figure 1.3: Historical and estimated global seafood demand MMT (Allen 2008)



Satisfying this increased demand will however not be trivial. From the 1950's landings of fish increased rapidly before stagnating around 90 million tons in the

1990's. Over the same period overexploited fish stocks have increased from less than 10 percent to 33 percent of the total stocks, while fully exploited stocks have reached 50 percent (FAO 2010b). Increased landings of fish are thus not possible. The growth in demand for seafood can therefore not be met by the world's capture fisheries, but must come from aquaculture farming and cultivation.

Figure 1.4: World capture fisheries production (FAO 2010)



Aquaculture farming has grown rapidly since the 1980's and in 2008 the production was at 58 million tons. It is estimated that aquaculture will meet more than 50 percent of global food fish consumption by 2012 (FAO 2010b). Efforts to develop the sector's full potential and increase seafood supplies have been aggressively pursued in recent years, often under regulatory regimes that support industry expansion and growth. Species bred varies over the globe, with tilapia, salmonoids, carp and crustaceans as the main species. In 2007, the proportion of the cultivated fish that is indigenously carnivorous was 31 percent (cf. figure 1.3 and 6.2) while 69 percent were non-carnivorous species. The digestive system for carnivorous fish is not accustomed to untreated plant materials and therefore the first aquaculture farmers used feed consisting mainly of fishmeal, which is ground and dried fish, in addition to fish oil. Non-carnivorous species were also fed fishmeal because it enabled more rapid and stable biomass growth than diets consisting only of vegetable meals (Naylor et al. 2000). But as fishmeal traded at a higher price than other protein-containing substances, feed producers started including other materials in the feed diets. Treated vegetable meals and oils were increasingly used in diets, replacing some of the fishmeal and fish oil. This was however not straightforward, as plant materials contain anti-nutrients which slow down the growth of the fish, thus lengthening the production time and increasing costs. As nutrition research progressed feed producers were able to replace more and more of the fishmeal with other substances, but still a fishmeal inclusion rate of 15 – 30 percent is necessary for many species.

Aquaculture farming's dependency on fishmeal has caused a growing concern that expansion of the industry might be limited, as the yearly output of fishmeal cannot be increased due to fully utilized sourcing stocks. This means that aquaculture production might not be able to meet the increased demand for seafood, because they do not have enough raw materials to do so. This potential bottleneck has received a lot of attention in recent years, both from private and governmental organizations.

Two papers (Wijkström and New 1989 and New and Wijkström 1990) in the early 1990's expressed concern about the use of marine resources for aquafeeds and coined the term "fishmeal trap" which became a common parlance in aquaculture. They stated that at some point in the future, farmers cultivating shrimp and carnivorous fish will run into a cost-price squeeze - the fishmeal trap - and that this might be the first of several 'ingredient traps' which might constrain certain forms of aquaculture in the future.

"The expected future expansion of global aquaculture, particularly of carnivorous species, has the potential to utilize about 70 percent of total global supplies of fishmeal by the year 2015 and to exceed the total supplies of fish oil well before that date," wrote FAO in a paper addressing the topic (New and Wijkström 2002). In 2003 aquaculture production consumed 53 and 87 percent of fishmeal and fish oil respectively (FAO 2009).

Knut Nesse, COO of Nutreco the world's leading salmon feed producer, said the following about their new plant in Aaverøy, Norway: "This upgraded plant enables us to replace the limited raw materials fish meal with vegetable alternatives" (FIS 2011).

1.4 Problem to be addressed

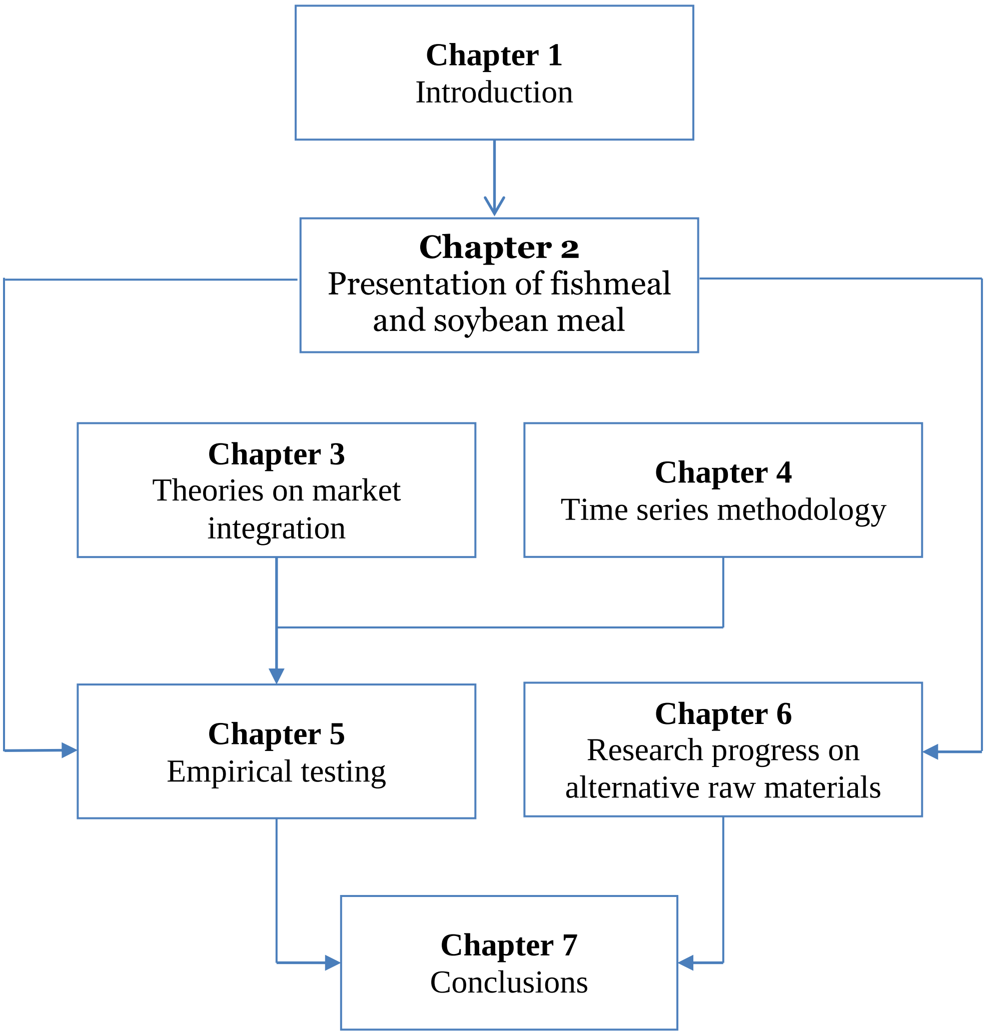
The overall goal for this paper is to investigate the validity of the fishmeal trap, i.e. will the limited supply of fishmeal hinder expansion of the aquaculture sector or are the expressed concerns unjustified? I will in this thesis not focus on the lacking availability of fish oil which is equally or more pressing than the fishmeal situation for some species, and especially for salmon (EWOS 2011). This is because fish oil come from the same sources as fishmeal, there are compared to fishmeal similar substitution possibilities, and research initiatives on alternatives to fish oil are often done coincidently with research on alternatives to fishmeal.

To answer the thesis' question I will first investigate the fishmeal market's relationship to one of its most popular substitutes; soybean meal (Chapter 5). As will be explained in Chapter 3, if the fishmeal and soybean meal markets exhibit a close relationship one might argue that market agents regard them as substitutes. Furthermore, this will imply that the industry's ability to switch between fishmeal and other protein containing meals is better than what some might have claimed, and concerns regarding the fishmeal trap might be therefore be unjustified. However, if the market integration relationship appears to have been deteriorating as the aquaculture industry has consumed an increasing share of global fishmeal supply, one might argue that there is a growth-limiting dependency on fishmeal. Chapter 2 will provide an introduction to the fishmeal and soybean meal markets, while Chapter 4 provides theoretical foundation to the statistical techniques applied in Chapter 5.

After investigating the fishmeal – soybean meal market relationship, a review of the progress made on aquaculture feed research will follow in Chapter 6. The aim of this section is to give a qualitative assessment of how promising these initiatives might be when it comes to replacing fishmeal in diets, and discuss future implications for the aquaculture sector.

Finally, the statistical observations and thoughts on feed research initiatives will be linked, and a discussion of the validity of the fishmeal trap will follow.

Figure 1.5: Paper flow chart



2 Presentation of fishmeal and soybean meal

This chapter will provide an introduction and overview to the fishmeal and soybean meal markets. Essential information about production, trade and consumption of fishmeal and soybean meal, are necessary knowledge if one wishes to understand the dynamics between fishmeal and soybean meal which are explored in the subsequent chapters.

2.1 Production of fishmeal

2.1.1 The fishmeal production process and value chain

Fishmeal is a brown powder obtained after cooking, press drying and squeezing fresh raw fish or trimmings[3] from food fish. IFFO has estimated that in 2009 pelagic fish was used in 75 percent of all fishmeal production, while the remaining 25 percent came from trimmings. Pelagic species are ocean fish that swim in schools and live in the upper sea levels. Their source of food is mainly plankton and most pelagic species are considerably fattier than other fish species. Historically, landings of fish have been around 90 million tons p.a. and about 1/3 of this has been converted into fishmeal and fish oil[4], while the remaining 60 million tons are marketed as fresh, frozen and canned fish.

Fishmeal contains typically 60 to 72 percent protein, 10 to 20 percent ash, 5 to 12 percent fat and has a high content of the fatty acids EPA and DHA; more commonly referred to as omega-3 (IFFO 2011).

Fishmeal in its basic form has been produced for centuries and usage has varied from production of fertilizers to salmon feed. Nowadays, fishmeal is used primarily in feed production. Fishmeal and fish oil production has become a very thriving industry as both fishmeal and fish oil prices have soared (see figure 5.1 for fishmeal price data).

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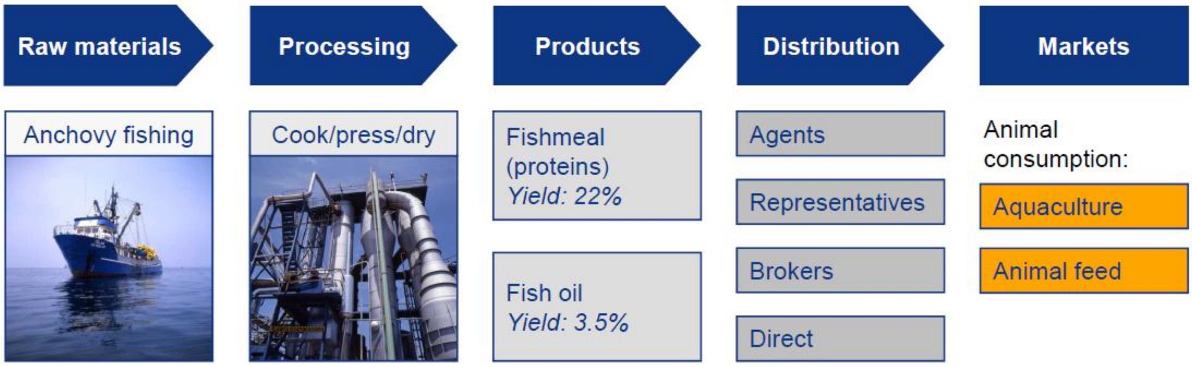
[3] Trimmings are left-overs from fish production to human consumption, e.g. head, fins, etc. left after fileting a fish

[4] Fish oil is a bi-product of fishmeal production and currently mostly used in aquaculture production

The Peruvian fishmeal and fish oil producer Copeinca has illustrated how the value chain in the industry is formed.

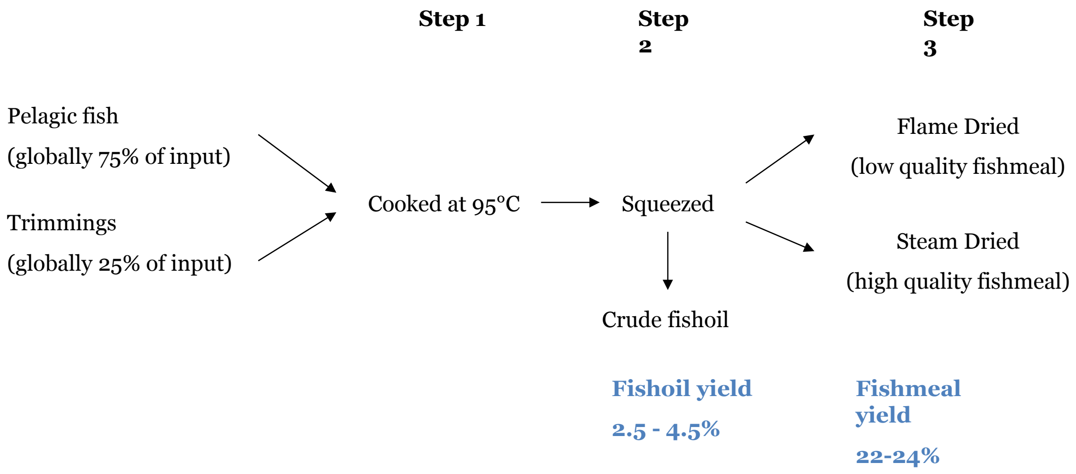
Figure 2.1: The fishmeal and fish oil value chain (Copeinca 2010)



The production process can roughly be described in three steps: First the fish is inspected, cleaned and cooked at about 95 ° Celsius. This process helps sterilize the fish as well as separate out proteins and oils. The cooked fish is squeezed to free most of the remaining liquids, and the material is then dried and ready to be sold (IFFO 2011). Fishmeal can be grouped into four product categories:

- High quality – used mainly for small-scale aquaculture units (e.g. trout farms)
- Low temperature meal – produced by steam drying, is highly digestible which nurtures rapid growth, and is thus especially suitable in salmon farming and piglet production
- Prime – meal with a protein count between 66 and 68 percent
- Fair Average Quality (FAQ) – flame dried meal with a lower protein count (direct fire causes proteins to disintegrate)

Figure 2.2: Production of fishmeal and fish oil



2.1.2 Global production

Global production of fishmeal is concentrated around a few top producers; top ten manufacturers in 2007 made up approximately 80 percent of the global production. Today Peru is the largest producer, China the second, Chile the third and then the Nordic countries Norway, Denmark and Iceland follow as the most important producers. There are approximately 300 dedicated plants worldwide that produce about 6.3 million tons of fishmeal and 1.1 million tons of oil annually from roughly 33 million tons of whole fish and trimmings (FIN 2010). The species used in production vary from region to region, but generally speaking it consists of small, bony, pelagic fish that has little or no commercial value as fish for direct consumption[5] (FAO 1986). It is estimated that about 90 percent of the fish species used to make fishmeal is “presently unmarketable in large quantities as human food” (Bose et.al 1991). See table 2.1 for an overview of the different species used around the globe.

The global fishmeal output has remained at 6 to 7 million metric tons p.a. for the last 20 years, while world trade has averaged around 3 to 4 million tons. Fluctuations in output and export level are naturally linked to variations in landings of fish used for fishmeal production. Overfishing and unsustainable fishery management has caused

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[5] Fish for direct consumption is fresh, frozen or canned fish marketed as human food, i.e. not used as animal feed.

some of this variation, but the large deviations are mainly due to the El Niño phenomena.

Figure 2.3: Global production of fishmeal (FAO Fishstat 2009)

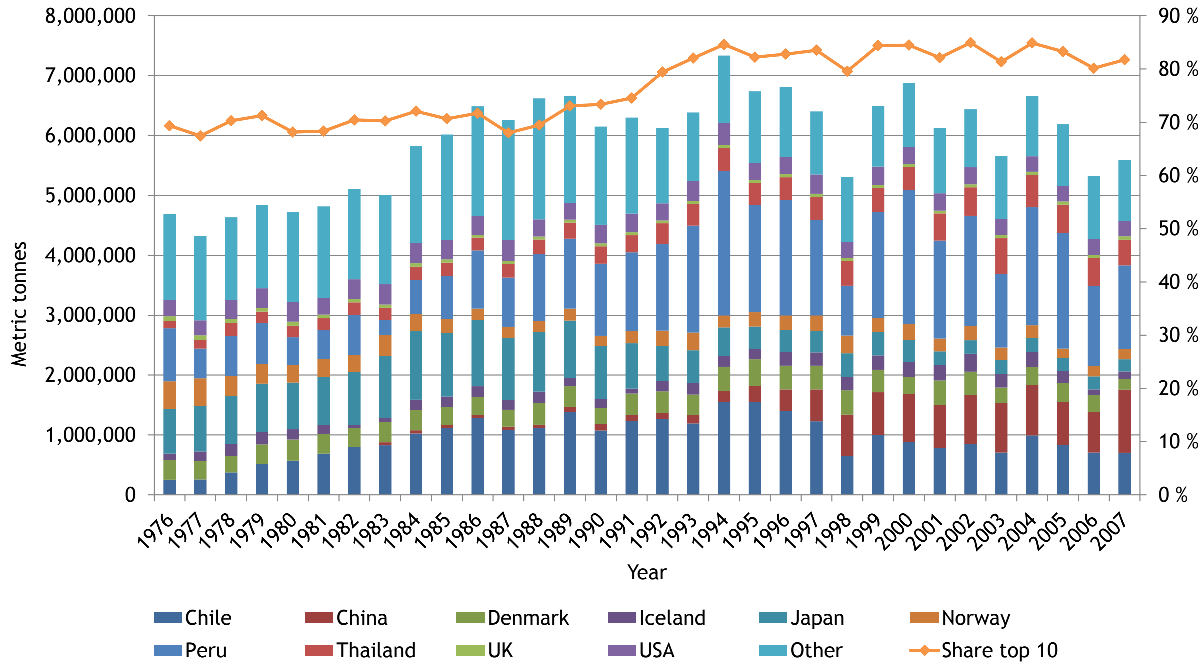

Table 2.1: Main species and share of global output and export (FAO Fishstat 2009)

Country/Region of production	Main species used in production	Global production share 2007	Global export share 2007
Peru	Anchovy	25 %	41 %
Chile	Jack Mackerel, Anchovy, Sardines	13 %	16 %
China	Various	19 %	0 %
Thailand	Various	8 %	3 %
USA	Menhaden, Alaska pollock	5 %	3 %
Iceland	Blue-whiting, Herring, trimmings	2 %	4 %
Norway	Blue-whiting, Capelin, trimmings	3 %	1 %
Denmark	Sandeel, Sprat, Blue-whiting, Herring	3 %	5 %
Japan	Sardine, Pilchard	4 %	0 %
Total		**81 %**	**73 %**

2.1.3 El Niño

The El Niño is a disruption of the ocean-atmosphere system in the Tropical Pacific having important consequences for weather and climate around the globe (Philander 1990). A mild El Niño occurs every 2 to 7 years and typically lasts from 9 months to 2 years. Major El Niño events (major meaning long-lasting and/or highly influential) have on average occurred every 26 years[6] (NOAA 2011). El Niño means The Little Boy or Christ Child in Spanish, and this name was chosen since the event arrives most often around Christmas time. Among the consequences are increased rainfall across South America, drought in the West Pacific, and a shift in the Pacific Trade winds.

In normal, non-El Niño conditions, the trade winds in the South Pacific blow towards the coast of Australia and Asia. These winds push warm water towards the west Pacific and the effect is so strong that the sea surface is about ½ meter higher around Indonesia than in Ecuador (NOAA 2011). When warm water is pushed away, the laws of physics dictate that it must be replaced by something else and thus deep, cold, nutrient rich water seeps up towards the coast of South America. This process is called upwelling and is what (among other factors) fuels the large schools of fish present around the eastern Pacific (Coull 1993). During El Niño years this nutritious process can collapse and the fish is driven deeper and away from the shorelines of South America. This makes it harder to catch and landings are reduced significantly. With Peru and Chile as the most prominent fishmeal producers in the world (responsible for approximately 40 percent of the global output), the El Niño can have a significant adverse effect on global supply of fishmeal.

2.1.4 South American Fisheries

The El Niño's destructive force on South American fisheries becomes apparent when viewing historical landings in Peru and Chile. From 1950 to 2008 there were three major El Niños: 1972/73, 1983 and 1998, and fishery landings were reduced by 50 to

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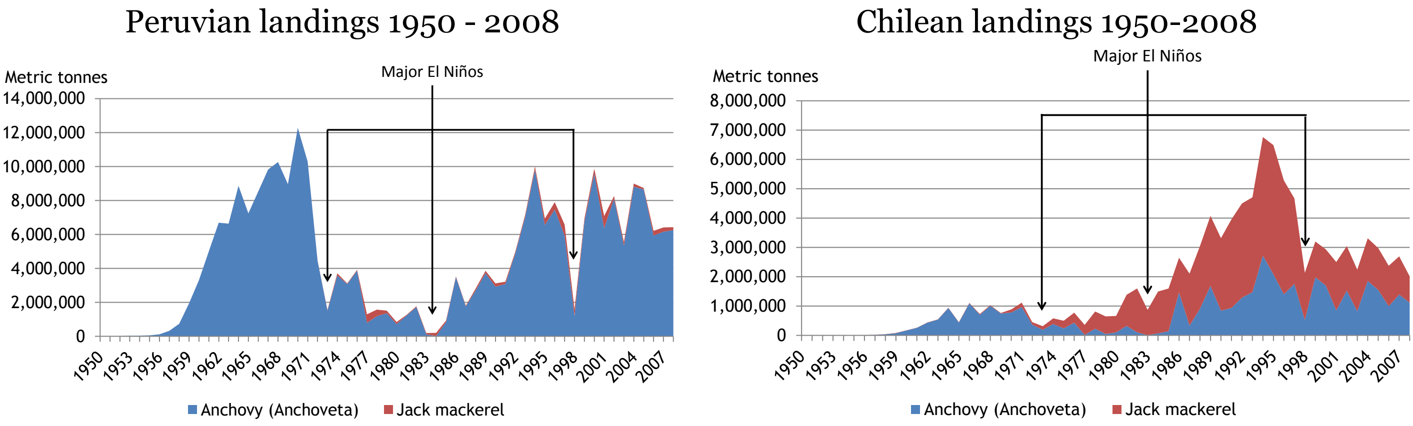
[6] Major El Niños were recorded in years 1790-93, 1828, 1876-68, 1891, 1925-26, 1972-1973, 1982-83, and 1997-98. I.e. 8 major El Niños the last (1998 – 1790) 208 years, which average (8/208) one every 26 years.

90 percent compared to the year before. Historically, overfishing has been a big problem in South America and combined with an El Niño event it nearly depleted the anchoveta schools during the 1970's. The stocks recovered throughout the decade, but overfishing caused a man-made stock cycles that coincided with a major El Niño in 1998 and once gain almost eradicated the anchoveta. After 2000 improved regulatory fishery schemes have been introduced in both Peru and Chile, with reduced quotas and increased resources to the fight against poaching of fish.

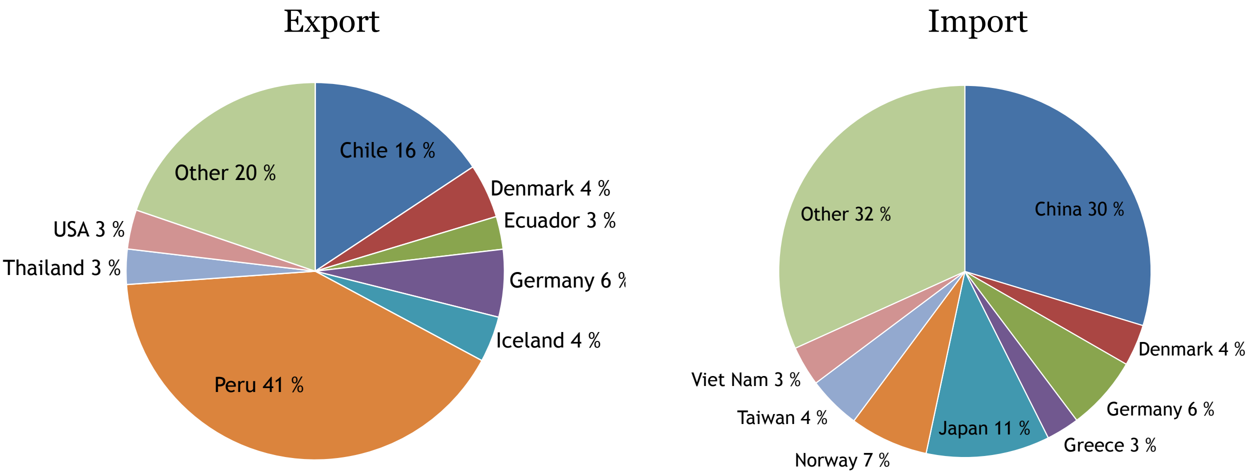
Figure 2.4: Peruvian and Chilean landings (FAO Fishstat 2009)



2.2 World trade of fishmeal

Approximately 60 percent of world fishmeal production is each year exported and not consumed in the manufacturing country, meaning world fishmeal trade equals about 3-4 million tons each year. Excluding China, which is a net-importer of fishmeal, the world trade share is raised to over 70 percent. Peru and Chile contribute about 60 percent of the globally exported fishmeal, and this further underlines the importance of the South American fisheries to the fishmeal market. The statistics show that even though China is one of the world's biggest fishmeal producers, is also by far the biggest importer of fishmeal with 30 percent of the global trade volume in 2007. Following China are the Asian nations Japan (11%), Taiwan (4%) and Vietnam (3%). The Scandinavian nations and Germany are involved in much intra-European trade (both importing and exporting fishmeal) and their figures should therefore be interpreted with caution.

Figure 2.5: World fishmeal export and import 2007 (FAO Fishstat 2009)



2.3 Consumption of fishmeal

2.3.1 Consumption by region

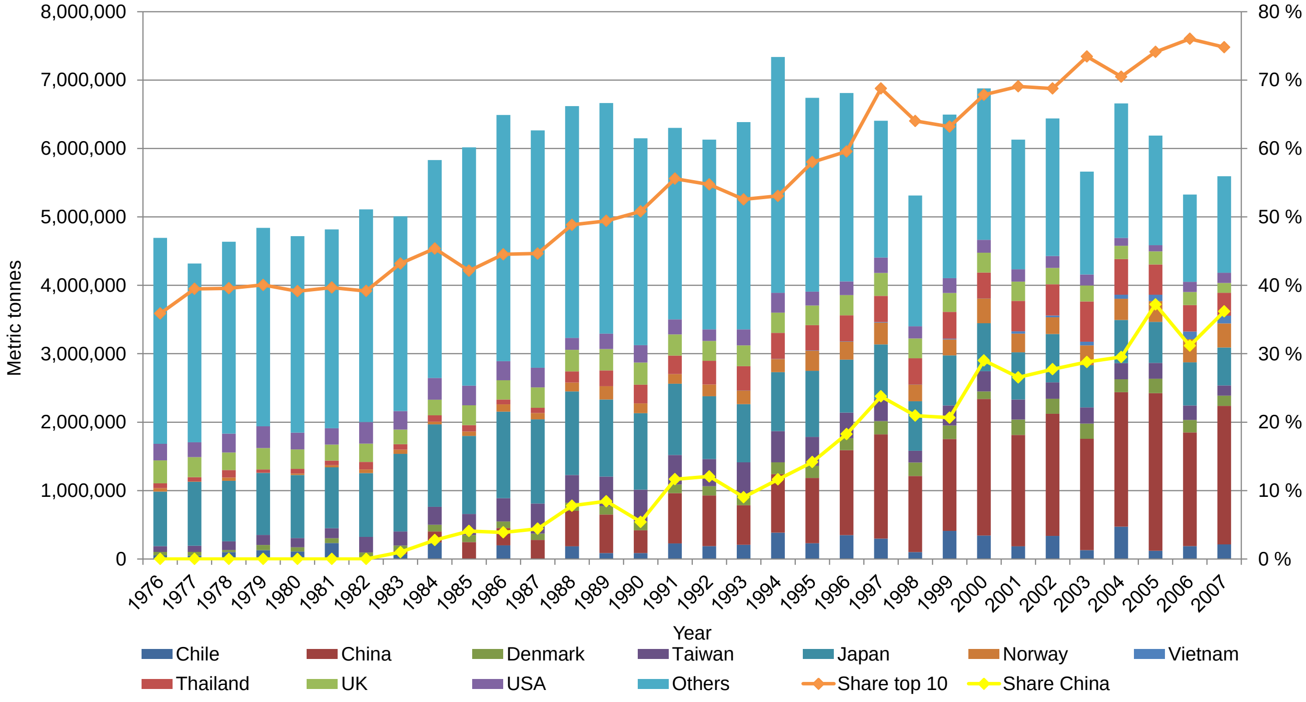
As an estimate of consumption, I have used FAO's FISHSTAT database and calculated the following relationship:

(2.1) $$\text{Consumption} = \text{Production} + \text{Import} - \text{Export}$$

Factors like country-intermediary storage and lagged/premature dating could cause some of the data to shift to one of the adjacent years in the sample and thus alter the consumption estimate. These effects are however considered negligible in most of the years, and not affecting the goal of providing a presentation to the biggest fishmeal consumers in the world.

Like global production of fishmeal, global consumption is to large extent concentrated around some key players. China is by far the greatest consumer, with a fishmeal consumption level ranging in between 1.6 and 2.0 million metric tons (MMT) annually. Japan then follows with a consumption of about 0.7 MMT, Thailand with about 0.4 MMT and Norway has around 0.35 MMT annually. China has been the main driver for the increasing consumption concentration, as they have gone from consuming 3 percent of world fishmeal production in 1985 to nearly 40 percent in 2007. As China imports around 1.2 MMT fishmeal annually (around 1/3 of total world trade) their demand is a significant factor in the forming of fishmeal prices.

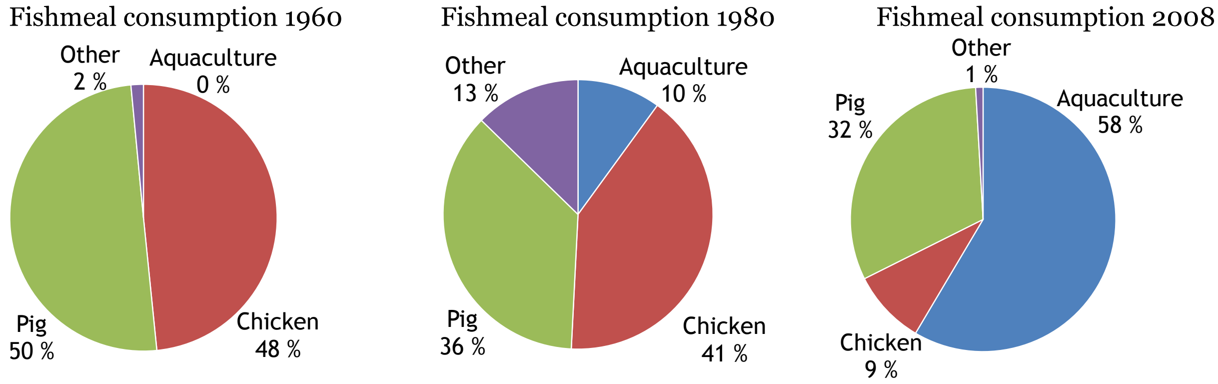
Figure 2.6: Global consumption of fishmeal (FAO Fishstat 2009)



2.3.2 Consumption by sector

As mentioned in the introduction, fishmeal has historically been used for several different purposes. In the 1960's fishmeal was used almost exclusively in pig and poultry production as the high protein content combined with health enhancing acids provided rapid and stable biomass growth (see figure 2.7 for an illustration of the change in consumption structure). From the 1960's onwards the aquaculture sector expanded production and thus its share of world fishmeal production rose (development in aquaculture farming production showed in appendix figure A.1). Since fishmeal has a high content of nutrients particularly favorable in aquaculture production, e.g. omega-3 acids (IFFO 2005 and Connor 2000), aquaculture farmers attach a higher premium to fishmeal over vegetable proteins, than what pig & poultry producers will do. Therefore, the tilting towards a larger fishmeal consumption share for the aquaculture sector is not only driven by the expansion of the sector itself, but also because it compared to pig & poultry producers has poorer substitution options.

Figure 2.7: Consumption share development (IFFO 2010)



From the 1960's the aquaculture sector has grown into the far most important consumer of fishmeal. A more detailed view of the dynamics in this change can be obtained by viewing consumption share data gathered from fishmeal research papers which is listed in table 2.2.

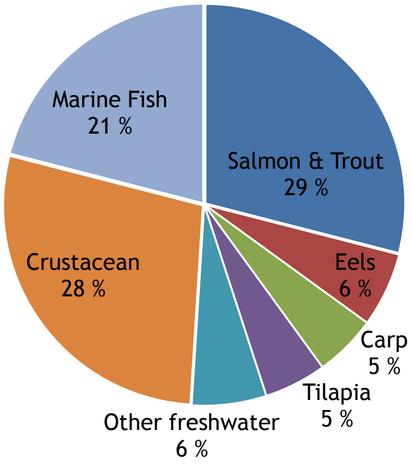
Aquaculture's share of about 10 percent remained stable throughout the 1980's, before it increased fourfold over the next decade. A drop in 1998, which coincided with a major price hike in fishmeal prices, was followed by further increments in the consumption share. These numbers are interesting when it comes to understanding the dynamics behind the trade and valuation of fishmeal. For now I will only underline that a change in consumption structure has over time taken place, and how this change has come about will be discussed in the following chapters.

Table 2.2: Fishmeal production and use (Kristofersson 2007a)

Year	**World**	**Aquafeed**	
	‘000 MT	use ‘000 MT	% of world
1980	5000	250	5 %
1981	5100	306	6 %
1982	5400	351	7 %
1983	5300	371	7 %
1984	6200	465	8 %
1985	6300	504	8 %
1986	6700	570	9 %
1987	6570	624	10 %
1988	6900	759	11 %
1989	7000	840	12 %
1990	6400	832	13 %
1991	6450	903	14 %
1992	6300	945	15 %
1993	6550	1048	16 %
1994	7500	1275	17 %
1995	6950	1946	28 %
1996	6900	2139	31 %
1997	6600	2442	37 %
1998	5340	2563	48 %
1999	6650	2727	41 %
2000	7050	3032	43 %
2001	6200	3100	50 %
2002	6250	3313	53 %
2003	5300	3816	72 %
2004	6300	4095	65 %
2005	6000	4320	72 %
2006	5700	3819	67 %
2007	6000	3660	61 %
2008	4970	2850	58%

Figure 2.8 shows how the consumption of fishmeal within the aquaculture sector was divided in 2008. Salmonoid production is now the biggest group of consumers, and this change has come about the last decade as salmon and trout farming has expanded. It constitutes however only a part of total aquaculture fishmeal consumption, which contradicts what some anti-salmon farming lobbyist might claim sometimes. Other important sources are crustacean production mainly done in China (prawns, crawfish, etc.) and marine fish.

Figure 2.8: Fishmeal consumption within aquaculture 2008 (Jackson 2010)



2.4 Substitutes for fishmeal: Soybean meal

2.4.1 Protein rich substitutes

Farmers and feedstuff producers value fishmeal mainly because of its high protein content and health enhancing nutrients. These characteristics are however not only found in fishmeal, but to different degree also in vegetable based products like rapeseed, soybean, corn and gluten. It is also possible to use terrestrial byproducts like meal from meat, blood, bone and feathers. Alternative marine-based substitutes from crustaceans, krill and algae are also useable as substitutes, and these sources may become more important in the future (Tacon 2008).

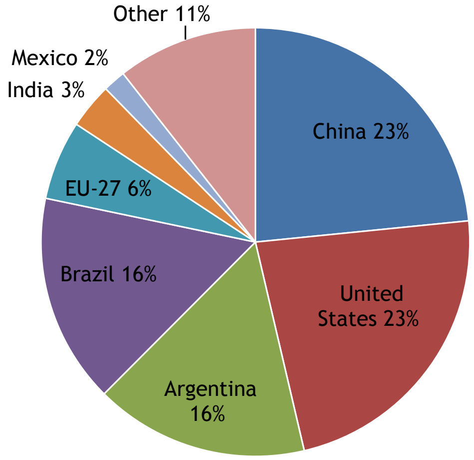
The common denominator of all of these organic substances is that they have a high content of protein and some contain omega-3 acids. Soybeans have a particularly high protein content and also contain favorable acids which have made it a very common substitute and complement to fishmeal. Since soybean meal is the most fitting and widespread vegetable alternative to fishmeal, I will in the statistical examinations in this paper focus on the relationship among fishmeal and soybean meal. A qualitative discussion of other vegetable substitutes will follow in chapter 6.

2.4.2 Production of soybeans

Soybean meal is the most used vegetable protein feed in the production of animal feeds. The production process is similar to that of fishmeal: The beans are crushed and then cooked to approximately 60°C. The beans are then squeezed to remove any liquids, then toasted and subsequently cooled. Depending on whether the hulls removed prior to cooking are added back to the mixture or not, the soybean meal will have a protein content of 44 to 47 percent.

The US has historically been the largest producer of soybean meal in the world followed by China and South American countries. In the 2009/2010 harvest[7] the total world production was 165 million tons of soybean meal, which is about 25 times the global fishmeal production. The US and China were each responsible for 23 percent of total world production in the 09/10 season, and it is estimated by the USDA that China will surpass the US in the forthcoming years as the leading producer of soybean meal to meet its increasing demand for protein (USDA 2007). Brazil and Argentina each had 16 percent of the 2009/2010 global harvest while the EU, India and Mexico produced 6, 3 and 2 percent respectively. This means that the top four producers of soybean meal hold nearly 80 percent of the global production.

Figure 2.9: World production of soybean meal 2009/2010 (USDA 2011)



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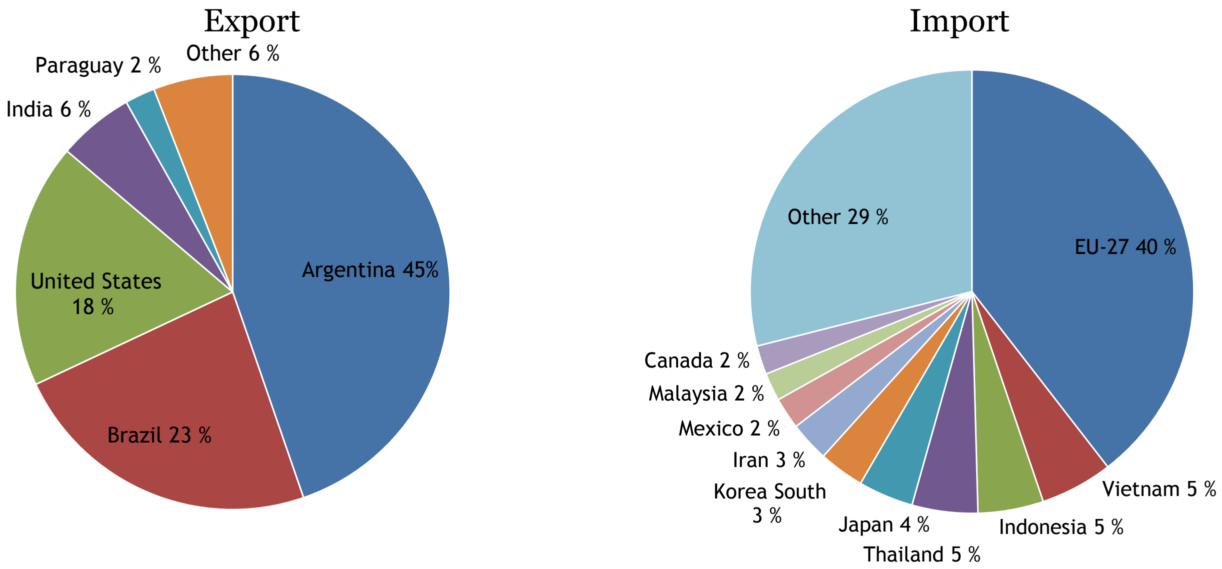
[7] USDA (United States Department of Agriculture) produces data based on the harvest cycle which starts 01. October and ends 30. September next calendar year, i.e. 2009/2010 is October 2009 to September 2010

2.4.3 Trade and consumption of soybeans

While about 60 percent of all fishmeal production is exported, only 30 percent of all soybean meal production is globally traded. One important reason for this is that the biggest soymeal producers, China and the US, consume all or large parts of their crops each year. Many producers also prefer to import whole soybeans and produce the meal themselves, thus this will disappear in the official numbers. China has developed from being a major exporter of soybean meal to being the biggest importer in the second half of the 1990's. As their production of soybean meal rose during the 2000's their import quantity however declined, and they traded a non-significant amount of soybean meal in 2009/2010 (USDA 2011). Today, the most significant exporters of soybean meal are Argentina, Brazil and the US, while the most prominent importers are the EU-27 and East-Asian countries.

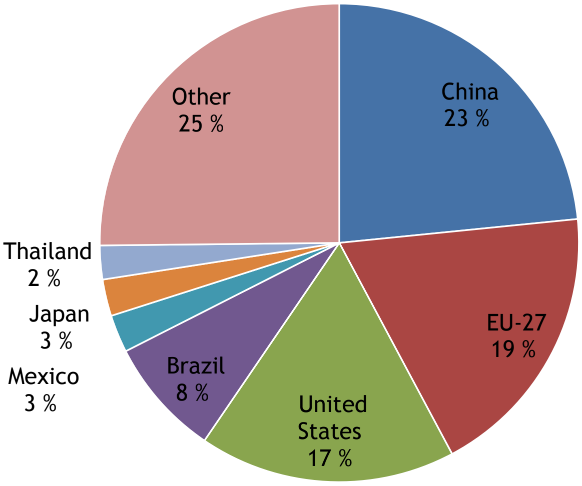
It is interesting to notice that the trade pattern of soybean meal and fishmeal show similar regional characteristics: net exporters are found in South America while important consumers are found in East Asia and the EU.

Figure 2.10: World soybean meal export and import 2009/2010 (USDA 2011)



Combining the USDA data from production, export and import a consumption overview can be established. This shows that China is the largest consumer of soybean meal, closely followed by EU-27 and the US.

Figure 2.11: World soybean meal consumption 2009/2010 (USDA 2011)



3 Theories on market integration

This chapter will provide information on economic theory and explore how goods of different substitutability have interrelated market effects. This will in turn be used to discuss how closely related the fishmeal and soybean meal markets are, thus helping determining if feed producers view them as substitutes.

3.1 Approaches to delineation of the economic market

Theories regarding the economic market place are something scientific scholars have been working on for centuries and the concepts of "supply and demand" have for a long time been the main pillars. From a theoretical stand point this idea is simple and good, but from a practitioners view there are several complicating issues.

First, what constitutes and confines a market? Cournot defined the market in the following way: "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).

George Stigler (1985) defined a market as "the area within which the price of a good tends to uniformity, allowances being made for transportation costs." This essentially means that prices of goods considered to be in one market could deviate from each other in the short run, but arbitrage or substitutability will force them to revert to a relation-equilibrium in the long-run. The Law of One Price (LOP) is a theorem that incorporates this idea by stating a relationship that two goods must uphold in the long run. It can be expressed by the following equation (Ashce et al. 1999):

$$(3.1)\quad \ln p_t^1 = B + \ln p_t^2$$

where p_t^1 and p_t^2 are the price of goods 1 and 2 respectively, and B is an adjustment factor. If $B = 0$ then the two prices are equal and we have the strict version of LOP. But restraining B to be zero makes the application in market integration testing limited. In order for $B = 0$ you must e.g. have a homogenous product, geographical proximity, no or equal governmental regulations, no or equal trade barriers, and enough market operators to ensure liquidity. Richardson (1978) tested for arbitrage in the trade between Canada and the US of 22 commodity groups. He found no evidence of perfect commodity arbitrage, but when applying a less strict market integration definition he found that the hypothesis of commodity arbitrage could not be rejected for 9 out of the 22 groups. This illustrates the problem of dealing with too strict criteria for market integration testing.

If you rather allow $\mathrm{B} \neq 0$ it means that there is a fixed-ratio value difference between the two goods, e.g. quality difference or difference in transportation cost. This is called the weak version of LOP.

Hicks and Leontief proposed an alternative representation that permits aggregation of sets of goods, called the Composite Commodity theorem or the Hicks-Leontief theorem. This theorem states that the relationship between two prices is constant, and it can be shown that this is closely related to the deterministic version of the LOP theorem. Hicks-Leontief hold if the trail of two price series can be described by the same common factor θ_t. We thus have:

(3.2) $p_t^1 = \theta_t p_0^1$ and $p_t^2 = \theta_t p_0^2$

by substituting the one equation to the other you get

(3.3) $p_t^1 = bp_t^2$

Where $b = p_0^1/p_0^2$. This means that in the long-run prices should move proportionally to each other. Since equation (3.1) is essentially the same as equation (3.3) with logarithms, the LOP- and the Composite Commodity theorem is closely related.

The weak version of LOP and the Hicks-Leontief theorem is thus a better approach to market delineation than more confined theories. The real interest from an economic standpoint is not to determine similar characteristics of two goods, but whether it exists a causal link between them so that the one of the goods or both of them affect the trade and/or price formation of the other. However, the equivalence in the spatial dimension between two goods could help to establish such a link. This connection might be upheld even though consumers experience quality differences among the products, they have only a small overlapping shared area of use and/or their production is geographically different. An example of this is Ashce, Bremnes and Wessels' work on the global salmon market (1999). The US International Trade Commision (USITC) had in a litigation where Norwegian salmon farmers were accused of dumping frozen Atlantic salmon in the American market, ruled that fresh Pacific Salmon and frozen Atlantic salmon could not be regarded as close enough substitutes to constitute one market. Asche et.al showed with time series analysis that the prices were integrated and that the two products therefore did compete in the same market. Thus even imperfect substitutes, in what some might consider being two separate markets, cannot be disregarded as factors affecting each of the goods price formation.

3.2 Examining how substitutes affects each other

The preceding discussion highlighted how goods, regarded as perfect or imperfect substitutes, can affect the trade and price formation of each other. This section will examine the theoretical implications of a price/quantity change in one of the goods in the following situations:

1. Good A and B are not substitutes
2. Good A and B are perfect substitutes
3. Good A and B are imperfect substitutes

3.2.1 A simple supply and demand model

Demand for a good is given by several factors, and the price of that good is only one of those factors. Other important demand driving characteristics are e.g. geographical proximity to the consumers, the existence of trade barriers, the number of market operators and the existence and price of substitutable goods. Incorporating all of these factors is both cumbersome and practically impossible, and a simplified demand function is thus often presented in the following way:

(3.4) $y_i^D = (a_i + b_i p_j + c_i I) + d_i p_i$

Where the demand for good i y_i^D is given by the exogenous factors $a_i + b_i p_j + c_i I$ and the endogenous factors d_i and p_i. The price intercept is denoted by a_i, the price of a substitutable good by p_j, the cross price effect by b_i, the income of consumers by I, and the income effect by c_i. Furthermore the demand is influenced by the price of the good itself p_i, and the demand effect of price d_i. Even though this demand model probably lacks several important demand driving factors, it will be sufficient to explore how the existence of substitutes may alter demand and thereby the price of a good.

The supply of a good can mathematically be described in the following way:

$$(3.5) \quad y_i^S = (e_i + f_i w_i) + g_i p_i$$

The price intercept is given by e_i, the input factor by w_i and the price of the input factor f_i. Supply is also influenced by p_i which denotes the price of the good, and the corresponding coefficient g_i which determines the price effect on supply. The variables $e_i + f_i w_i$ are thus exogenous variables while $g_i p_i$ are endogenous. Again, other possible important factors like transportation costs and economies of scale are neglected.

The point of presenting a mathematical framework is to illustrate how two goods affect the demand of each other. This sensitivity is measured by the cross-price elasticity. Elasticity (not cross-price elasticity) is a number that tells us the percentage change that will occur in a variable in response to a one-percentage increase in another variable. In the case of prices and demand, the elasticity measures the sensitivity of quantity demanded of good i to price change of good i. A cross-price elasticity of demand thus refers to the percentage change in the quantity demanded for a good that results from a one-percent increase in the price of another good.

The cross-price elasticity is measured as the percentage change in quantity of good i, divided by the percentage change in the price of good j.

$$(3.6) \quad E_{ij} = \frac{\%\Delta Q_i}{\%\Delta P_j}$$

Mathematically this constitutes the following:

$$(3.7)\quad \mathrm{E_{ij}} = \frac{\partial \mathrm{y_i^D} / \mathrm{y_i^D}}{\partial \mathrm{p_j} / \mathrm{p_j}} = \frac{\partial \mathrm{y_i^D}}{\partial \mathrm{p_j}} \frac{\mathrm{p_j}}{\mathrm{y_i^D}} = \mathrm{b_i} \frac{\mathrm{p_j}}{\mathrm{y_i^D}}$$

Where $\mathrm{b_i}$ is a measure of the relative change in quantity demanded for good i for a change in the price of good j, and is considered to be zero or larger.[8] The next sections will explore how different assumption about the substitutability of the goods will alter the cross-price elasticity.

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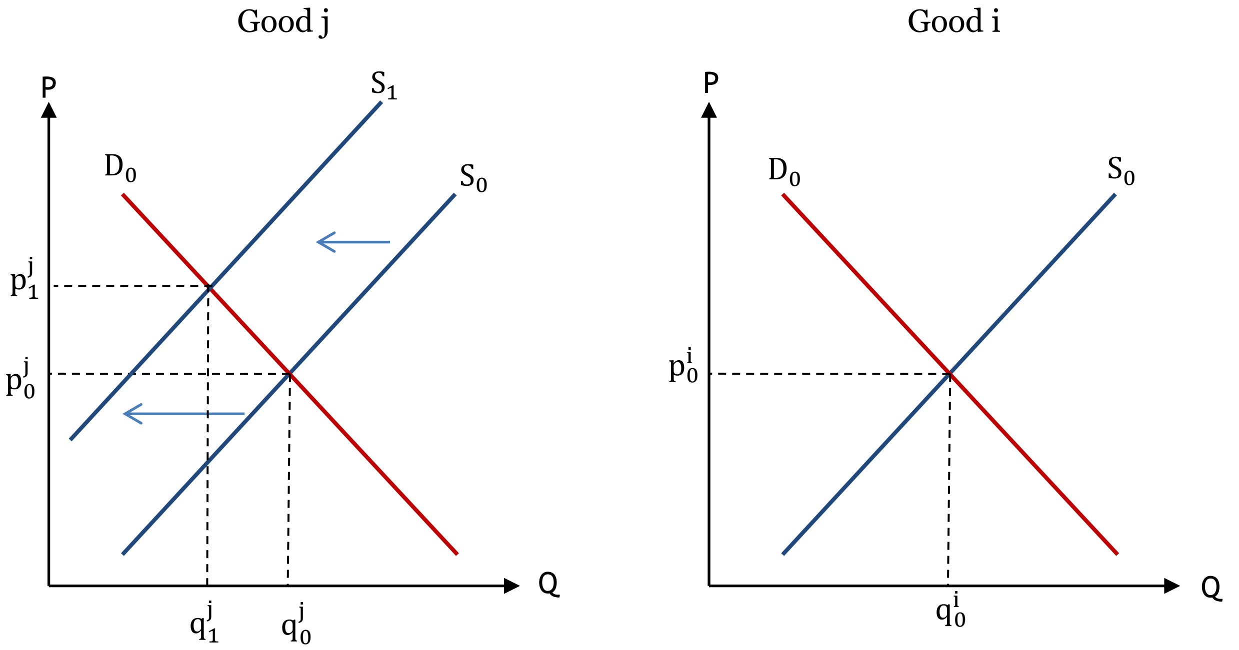
[8] Good i and j might be considered to be complementing goods, meaning that their aggregate value is greater when combined than when separate. This will alter the framework somewhat compared to how it is presented here.

3.2.2 The two goods are not substitutes

First consider the case where good i and j are not substitutes. E_{ij} will then be zero as there are no substitution effects. Initially the supply and demand for good j is in equilibrium with traded quantity q_0^j and a price p_0^j. The supply for good j is then reduced, and the new equilibrium is given by demand curve D_0 and supply curve S_1. The new equilibrium will now involve a lower traded quantity q_1^j, at a higher price p_1^j. Since $E_{ij} = 0$, it means that this price increase will have no effect on the demand for good i and there are no equilibrium changes for good i. The LOP principle is thus not valid for these markets.

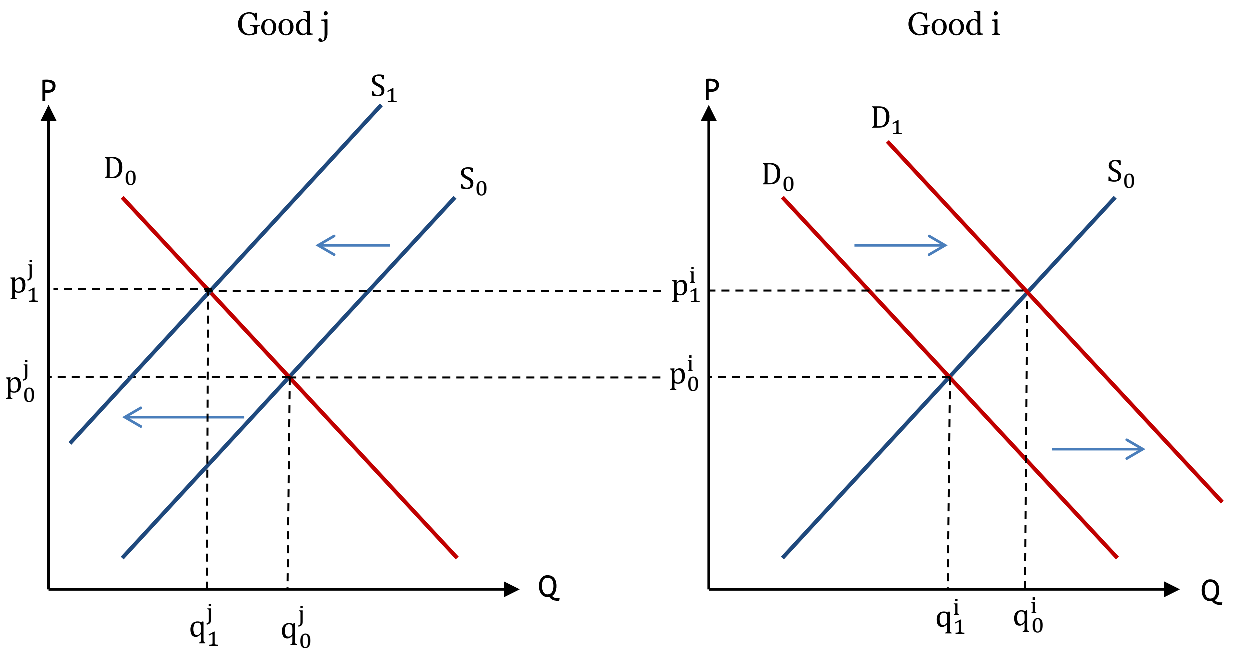
Figure 3.1: No substitution among the goods



3.2.3 The two goods are perfect substitutes

If the good i and j are perfect substitutes it means that consumers are indifferent to which one of the two goods they have. First consider that the markets are in equilibrium and the price of both goods are given by $p^j_0 = p^i_0$, and the quantity by q^j_0 and q^i_0 (not necessarily equal). The supply of good i is then reduced so the new equilibrium is given by q^j_1 and p^j_1. Since consumers are indifferent between the goods, they will start bidding up the price for good i until the prices are equal again, and thus the new equilibrium for good i is given by q^i_1 and p^i_1. Prices are then again equal between the two goods which means that the LOP applies and the markets are fully integrated.

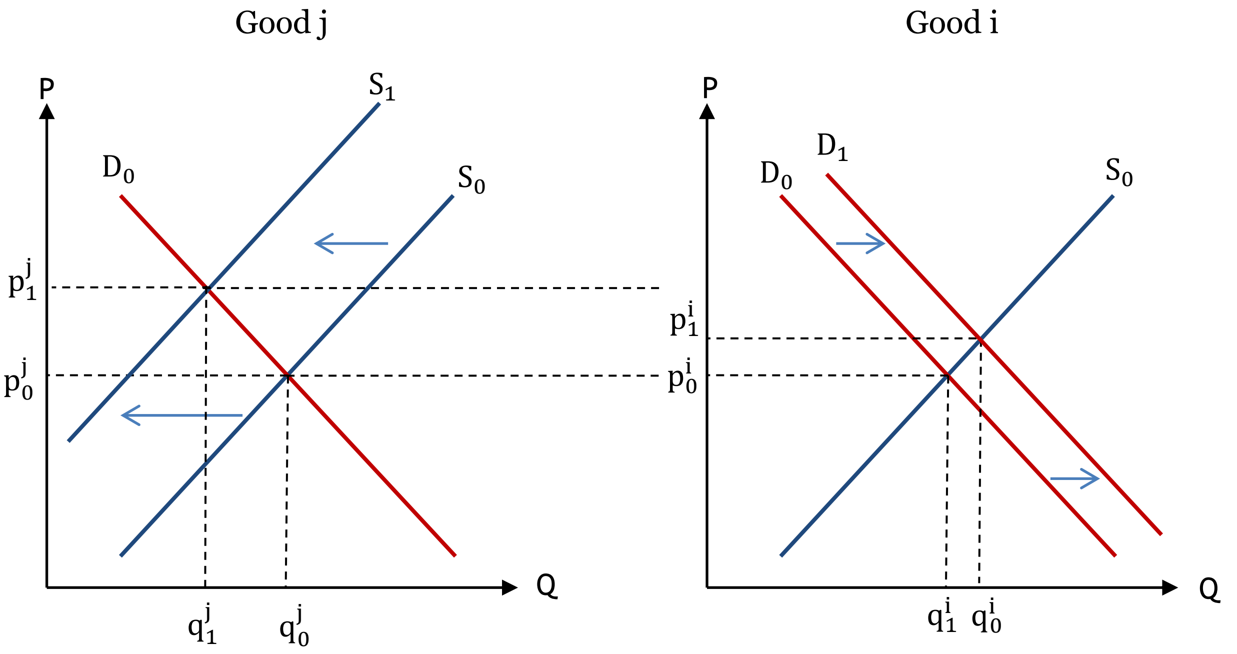
Figure 3.2: The two goods are perfect substitutes



3.2.4 The two goods are imperfect substitutes

As the last two cases, consider the supply of good j drops so that a new equilibrium is given by q_1^j and p_1^j. As the goods are imperfect substitutes, it means that $E_{ij} > 0$ and thus a price increase in good j will lead to a partial demand shift from good j to i. This demand shift will then increase the price of good i, but not as much as the price increase in good j. So the price change in the imperfect substitutes case is equal to the perfect case, only that the price and quantity transference is smaller. The weak LOP is thus applicable here, and the markets can be said to be partially integrated.

Figure 3.3: The two goods are imperfect substitutes



The three simple preceding examples showed how the degree of substitutability determines whether the markets are integrated and if the LOP holds. These examples were illustrated with changes in the quantity supplied, and with perfect information about the degree of substitutability and hence the cross-price elasticity. In practice however, it is not possible to observe the cross-price elasticity directly, and thus determining if the markets are integrated is not straightforward. But by using price data about the two goods and statistical procedures it is possible to trace how the price change for one good affects the price change of the other, thus determining how integrated the markets are.

As mentioned in the introduction, some have expressed concerns that the restrained global output of fishmeal will hinder aquaculture production growth. If it can be shown that fishmeal and soybean meal are “perfect” substitutes when accounted for the difference in protein content, then it means that fishmeal is only priced for its protein and no other qualities. Thus a limitation of the fishmeal output should not be worrisome for the future growth of the aquaculture sector. On the other hand, if soybean meal is found not to be a potential substitute for fishmeal, then the concerns might be well-founded as fishmeal is then valued for something else than its protein content. In practice, it is not likely that either of these “extreme” cases will be correct. What the aim of the analysis should be is to decide which way the relationship is leaning towards and how this again may influence future aquaculture production.

The next section will describe statistical methods that can be used to examine the relationship between the soybean and the fishmeal market.

4 Time series methodology

In the empirical tests in chapter 5, I will mainly use cointegration analysis to determine if the fishmeal and soybean meal market are integrated or not. Cointegration analysis is however not a straightforward topic and knowledge about more basic statistical concepts are necessary before the techniques behind cointegration can be established. I will therefore go through the basics before proceeding to the more advanced.

4.1 Cointegration analysis

4.1.1 Non-stationary time series

Non-stationary data series is an important topic in time series analysis, as failure to recognize a time series as non-stationary can lead to spurious regressions and false results. A stationary time series process is one whose probability distribution is stable over time in the following sense: if we take any collection of random variables in a sequence and then shift that sequence ahead s time periods, the joint probability distribution must remain unchanged (Woolridge 2009). A time series is thus called non-stationary when *one* of the following criteria is not fulfilled:

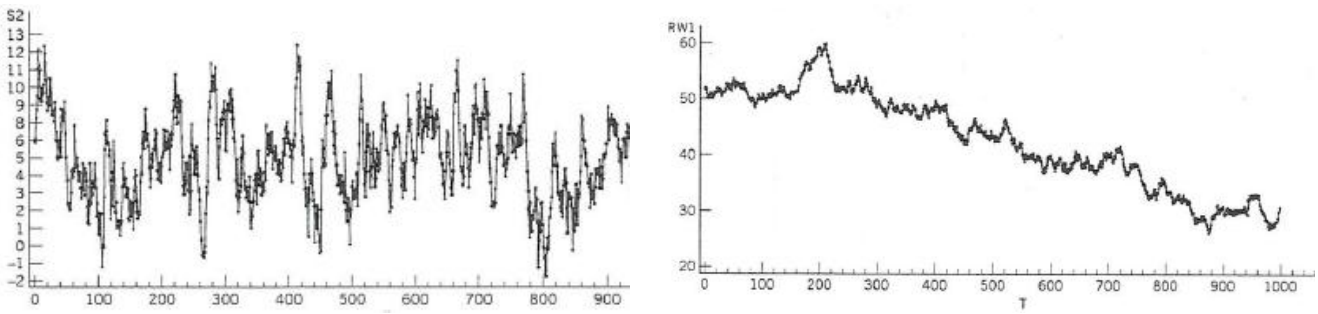
Statistical requirement	Practical implications
(4.1) $E(y_t) = \mu$	The expectation value must be equal throughout the data series
(4.2) $Var(y_t) = \sigma^2$	The variation must be constant
(4.3) $Cov(y_t, y_{t-s}) = \gamma_s$	The covariance depend only on the time interval (s) of the variable, not where in the time series (t) this distance is measured
	μ = Expected value, σ^2 = Variance, γ_s = Covariance

There are mainly three ways of determining whether a time series is non-stationary or not, and these will be explained in the next sections.

4.1.1.1 Visual examination

One of the methods is plotting the time series against time and visually examine if one of the three conditions are breached. Differences in mean and variance can be detected with this method, while time-varying covariance can be harder. In the following example the figure to the left does not emit any clear signals of non-stationarity and further testing is advised. The figure to the right shows a rather clear sign of a difference in mean, and even though more formal tests always are preferable it can be argued that the time series is non-stationary.

Figure 4.1: Example of stationary vs. non-stationary time series (Woolridge 2009)



Stationary time series

Non-stationary time series

4.1.1.2 Autocorrelation plots

A second method to determine if a time series is non-stationary is to construct a correlogram. A correlogram, also known as an autocorrelation plot, is a plot sample of autocorrelations[9] ρ_s versus time s. For a stationary time series we have the following covariance function

$$(4.4)\quad \text{cov}(y_t, y_{t+s}) = \gamma_s$$

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[9] The autocorrelation describes the correlation between values of a process at different points in time. More practically speaking, it shows how two data points tend to be related to each other when you have conditioned on a certain time span between them.

where y_t is the dependent variable at time t, and y_{t+s} the dependent variable at time t+s. γ_s is then the covariance denoted by the time span s. The autocorrelation function is given by the co-variance divided on the variance, thus we have

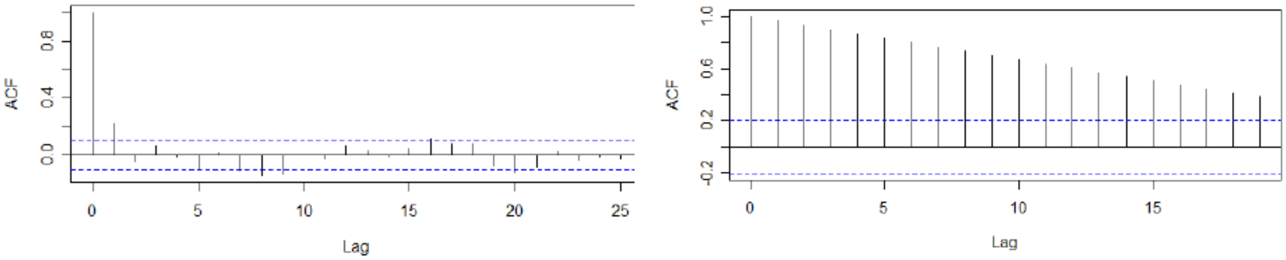
$$(4.5)\quad \rho_s = \frac{\mathrm{cov}(y_t, y_{t+s})}{\mathrm{var}(y_t)} = \frac{\mathrm{cov}(y_t, y_{t+s})}{\mathrm{cov}(y_t, y_t)} = \frac{\gamma_s}{\gamma_0}$$

The estimated sample correlation is then

$$(4.6)\quad \hat{\rho}_s = \frac{\hat{\gamma}_s}{\hat{\gamma}_0}$$

and a plot of $\hat{\rho}_s$ against s gives you a correlogram.

Figure 4.2: Example of detecting autocorrelation with an autocorrelation plot



No clear indications of autocorrelation

Clear indication of autocorrelation

In the left hand illustration, the autocorrelation function stays within the 95 percent confidence bands for almost all observations and there is thus no clear indication of autocorrelation. The right hand graph gives a clear indication of an autocorrelated time series which is thus non-stationary.

4.1.2 Unit roots and Dickey-Fuller

4.1.2.1 Unit roots and the special case of random walks

Some time series are said to follow a “random walk”, which is a special case of a unit root process and non-stationary. It is called a random walk because the next period’s value is given by the last observation y_{t-1} and a stochastic (random) normal distributed process e_t. More formally we have

(4.7) $y_t = y_{t-1} + e_t$

This function does not breach the equal expectation criteria, but the variance[10] and covariance[11] will depend on t (time). However, if a time series constitutes a random walk it will have certain favorable statistical properties which can be utilized in cointegration analysis.

More generally, unit roots (without drift or trend) are denoted by

(4.8) $y_t = \gamma y_{t-1} + e_t$

Which corresponds to the random walk function when $\gamma = 1$. To determine if the function is a random walk or not, differentiate the function (i.e. subtract y_{t-1}), and examine if the new transformed function is still a random walk.

Differentiating (4.9) $y_t - y_{t-1} = (\gamma - 1)y_{t-1} + e_t$

---

[10] Proof why the variance depends on t (for simplicity assume that y_0 is non-random, i.e. $\mathrm{Var}(y_0) = 0$)

$\mathrm{Var}(y_t) = \mathrm{Var}(y_{t-1} + e_t)$

$= \mathrm{Var}(y_{t-2} + e_{t-1} + e_t) = \cdots = \mathrm{Var}(y_0 + e_t + e_{t-1} + e_{t-2} + \cdots + e_1)$

$\mathrm{Var}(y_t) = \mathrm{Var}(e_t) + \mathrm{Var}(e_{t-1}) + \cdots + \mathrm{Var}(e_1) = \mathrm{Var}(e_t) \cdot t$

I.e. the variance increases with t, breaches stationary condition given in equation (4.2)

[11] Mathematical proof that the covariance and the correlation coefficient depends on t (for simplicity, assume that y_0 is non-random, i.e. $\mathrm{Var}(y_0) = 0$)

$$\mathrm{Corr}(y_t, y_{t+s}) = \frac{\mathrm{Cov}(y_t, y_{t+s})}{\sqrt{\mathrm{Var}(y_t)} \cdot \sqrt{\mathrm{Var}(y_{t+s})}} = \frac{\mathrm{Var}(e_t)t}{\sqrt{\mathrm{Var}(e_t)t} \cdot \sqrt{\mathrm{Var}(e_{t+s})(t+s)}}$$

$$\mathrm{Corr}(y_t, y_{t+s}) = \sqrt{\frac{t}{t+s}}$$

Thus the correlation coefficient depends on the starting point t, which breaches stationary condition given in equation (4.3)

New function (4.10) $\Delta y_t = \theta y_{t-1} + e_t$

where $\Delta y_t = y_t - y_{t-1}$ and $\theta = (\gamma - 1)$

To perform a test for random walk one must examine if $\theta = 0$ with the following null and alternative hypothesis

$H_0\colon \theta = 0 \quad \rightarrow \text{i.e. the differenced series is not stationary}$

$H_0\colon \theta < 0 \quad \rightarrow \text{i.e. the differenced series is (assymptotic)stationary}$

The problem is that under H_0 we have a non-stationary process and the t-statistics will not have an approximate standard normal distribution, even in large sample sizes. Dickey & Fuller have created an asymptotic distribution of the t statistic under H_0 which can be used to get around this problem (Dickey-Fuller 1979).

4.1.2.2 Dickey-Fuller's test for unit roots

In general there are three different Dickey-Fuller test structures:

(4.10) $\Delta y_t = \theta y_{t-1} + e_t$	No intercept or time
(4.11) $\Delta y_t = \alpha + \theta y_{t-1} + e_t$	Intercept α, no trend
(4.12) $\Delta y_t = \alpha + \rho t + \theta y_{t-1} + e_t$	Intercept α and trend ρ

First it has to be decided whether to include a constant and a linear time trend, or neither in the regression. Including irrelevant regressors in the regression will reduce the power of the test to reject the null hypothesis of a unit root, however wrongly excluding regressors can give false results. E.g. a price series might have a linear trend, but be $I(0)$ around its trend and if this is not accounted for the series can be mistaken for a unit root process. The standard recommendation is to use both theoretical reasoning and visual examination of the plot in order to decide the test structure. E.g. if you try to determine if an interest rate constitutes a unit root, it does not make much sense to include a drift term, because you will not expect interest rates to decrease/increase indefinitely.

When a test structure is determined, run the regression and obtain the t-values of the lagged variable. The t-statistic is then compared to the critical value relevant to the chosen test structure and confidence level.

Table 4.1: Dickey-Fuller critical values (Dickey-Fuller 1979)

	Significance level		
	2.5%	5%	10%
No intercept or trend	-2.23	-1.95	-1.62
Intercept α, no trend	-3.12	-2.86	-2.57
Intercept α and trend ρ	-3.66	-3.41	-3.12

If a time series is non-stationary prior to differentiating it, but stationary afterwards, it is said to be integrated of order one, I(1). When performing tests one should be aware that the Dickey-Fuller tests assume that the errors are independent and have a constant variance.

4.1.2.3 The augmented Dickey-Fuller test

Not all time series variables can be well represented by the first-order autoregressive process given in the previous section (autoregressive refers to the lagged variable). But it is possibly to extend the test structures with additional lagged variables and this extended model is called the augmented Dickey-Fuller test. New test structures will be (Enders 2010a):

$$(4.13)\quad \Delta y_t = \theta y_{t-1} + \sum_{k=2}^{p} \beta_k \Delta y_{t-k+1} + e_t \qquad \text{No intercept or time}$$

$$(4.14)\quad \Delta y_t = \alpha + \theta y_{t-1} + \sum_{k=2}^{p} \beta_k \Delta y_{t-k+1} + e_t \qquad \text{Intercept } \alpha \text{, no drift}$$

$$(4.15)\quad \Delta y_t = \alpha + \rho t + \theta y_{t-1} + \sum_{k=2}^{p} \beta_k \Delta y_{t-k+1} + e_t \qquad \text{Intercept } \alpha \text{ and drift } \delta$$

The new lagged variables and their corresponding coefficients are not of any direct interest, but they are used to clear up any autocorrelation in the data so that correct inference can be made. The relevant t-statistics will again depend on the deterministic components included in the regression, and they are the same as the one provided in the previous section (table 4.1).

This new structure provides a new challenge: How should one choose the correct number of lags? If too many lags are included then the test will have a low rejection power, but if too few are incorporated there will be autocorrelation left in the residuals and they will not behave as white noise processes. The best idea is to start with a relatively long lag length and look at the last lags significance. If it is non-significant, cut down one lag and repeat the procedure until the last lag is significant. In the pure autoregressive case such a procedure will yield the true lag length with an asymptotic probability of unity, provided the initial choice of lag length includes the true length (Enders 2010a).

4.1.3 Cointegration

This sub-chapter aims to explain what cointegration analysis is, why it is such a powerful statistical tool and how it is performed. All of the previous explained statistical methodologies will be helpful in order to understand this procedure.

Cointegration analysis deals with regressions made of two I(1) variables, say y_t and x_t. We will thus expect that any linear combination of these variables will also be I(1). An example of such a linear combination is:

$$(4.16) \quad e_t = y_t - \beta_0 - \beta_1 x_t$$

However, in some cases the linear combination will be a I(0) process (i.e. stationary). This happens when y_t and x_t share stochastic trends and their difference will then not diverge too far from an equilibrium. This is interesting from an economic point of view, because if two variables can be shown to be co-integrated it will help prove a hypothesis that the variables are driven by the same market forces. E.g. you can examine if spot and future prices on a stock market index share similar stochastic patterns, and thus if their price path is driven by the same underlying factors (which is highly likely).

There are several approaches to cointegration. Engle & Granger were among the first to give cointegration a formal treatment (1987a) and their approach has been extensively used by researchers. The Engle-Granger (EG) approach has however received some criticism. One problem is that the EG approach cannot adequately handle multivariate cases and that you have to decide which variable to normalize upon. However, in theory what variable you chose to normalize on should not alter the final results (Durand 1994). The Johansen procedure is deemed more suitable for multivariate systems and has resolved some of the issues with the EG approach since it is carried out in a Vector Auto Regressive (VAR) model. However, in the Johansen procedure you do have to place restrictions on the system, effectively normalizing on one variable. The Johansen approach is also relative to EG deemed more mathematically cumbersome to understand.

My dataset only covers two variables (i.e. not multivariate) and it is not hard to hypothesize which variable that should be normalized on. Thus the EG-approach should be an adequate methodology. Also, the latest research reports on the fishmeal-soybean meal relationship have been covered with the Johansen methodology and an analysis done with a different framework could therefore be interesting.

4.1.3.1 The Engle-Granger approach for two variables

Engle and Granger have developed a four-step procedure to determine if two I(1) variables are cointegrated of order CI(1,1), and this section describes these steps (Enders 2010b).

Step 1: Pretesting variables

Cointegration analysis requires by definition that the two variables are integrated by the same order, so the first step is to perform a Dickey-Fuller test for unit roots like described in section 4.1.2.2. If both variables prove to be stationary, there is no need for cointegration analysis since more standard statistical methods can be applied directly. If they are integrated of different order it can be concluded that they are not cointegrated.

Step 2: Estimating the long-run relationship

If step 1 proved that both of the variables (x_t and y_t) are I(1) then the next step is to evaluate the long-run relationship. The researcher must decide whether to include a trend term or not, and again this choice should be made by visually examining the data or applying economic reasoning:

No trend (4.17) $y_t = \beta_0 + \beta_1 x_t + e_t$

With trend (4.18) $y_t = \beta_0 + \rho t + \beta_1 x_t + e_t$

So if the variables are in fact co-integrated, the deviations from this relationship should be stationary. These deviations are found in the estimated residuals $\hat{e}_t$, and should be tested with the Dickey-Fuller procedure to find their order of integration. The Dickey-Fuller test without an intercept is appropriate as the residual sequence is obtained from a regression equation:

$$(4.19) \quad \Delta\hat{e}_t = a_1\hat{e}_{t-1} + \varepsilon_t$$

If we cannot reject the null hypothesis that $a_1 = 0$, it means that we cannot reject that the residuals contains a unit root. This means that x_t and y_t are not cointegrated. If the t-statistic is below the critical value we can conclude that the residual series appear to be stationary and that the two variables (x_t and y_t) are cointegrated. The critical values for this test differ from the values in the standard Dickey-Fuller test since we need to account for the estimation of $\tilde{\beta}$. The new critical values are the following:

Table 4.2: Critical values for cointegration test (MacKinnon 2010)

	Significance level		
	1%	5%	10%
No drift	-3.90	-3.34	-3.04
With drift	-4.33	-3.78	-3.50

If the residuals should not appear to be white noise, an augmented form of the test can be used to clear up the serial correlation.

The test is then

$$(4.20)\quad \Delta\hat{e}_t = a_1\hat{e}_{t-1} + \sum_{i=1}^{n} a_{i+1}\,\Delta\hat{e}_{t-1} + \varepsilon_t$$

and the critical values are the same as in table 4.2.

Step 3: Estimate the error-correction model

If the null hypothesis of no cointegration is rejected then the equilibrium relationship can be estimated with an error-correction model (ECM). The ECM stem from the time series analysis field developed by Box and Jenkins, and was initially used by economists in the 1970's to test equilibrium relationships postulated by economic theory. Researchers used this approach to model the behavior of economic variables as a dynamic process of adjustment towards an equilibrium relationship (Durand 1994).

The two prior steps in the Engle-Granger approach have been completed in order to establish that there exists a linear combination of the variables that is stationary. The ECM utilizes this fact in order to create a model with where valid inference and prediction is possible. The ECM equations are as follows (using long-run equilibrium definition from equation 4.17):

$$(4.21)\quad \Delta y_t = \alpha_1 + \alpha_y\left[y_{t-1} - \tilde{\beta}_1 x_{t-1} - \tilde{\beta}_0\right] + \sum_{i=1} a_{11}(i)\,\Delta y_{t-i} + \sum_{i=1} a_{12}(i)\,\Delta x_{t-i} + \varepsilon_{yt}$$

$$(4.22)\quad \Delta x_t = \alpha_2 + \alpha_x\left[y_{t-1} - \tilde{\beta}_1 x_{t-1} - \tilde{\beta}_0\right] + \sum_{i=1} a_{21}(i)\,\Delta y_{t-i} + \sum_{i=1} a_{22}(i)\,\Delta x_{t-i} + \varepsilon_{xt}$$

Where $\tilde{\beta}_1$ and $\tilde{\beta}_0$ is the estimated coefficient from equation (4.17), ε_{yt} and ε_{xt} are white noise processes, and a_{11}, a_{12}, a_{21} and a_{22} are parameters.

It is possible to simplify the representation by using the estimated residuals from (4.17) (Engle and Granger 1987b), and this is of great practical help:

$$(4.23)\quad \Delta y_t = \alpha_1 + \alpha_y \hat{e}_{t-1} + \sum_{i=1} a_{11}(i)\,\Delta y_{t-i} + \sum_{i=1} a_{12}(i)\,\Delta x_{t-i} + \varepsilon_{yt}$$

$$(4.24)\quad \Delta x_t = \alpha_2 + \alpha_x \hat{e}_{t-1} + \sum_{i=1} a_{21}(i)\,\Delta y_{t-i} + \sum_{i=1} a_{22}(i)\,\Delta x_{t-i} + \varepsilon_{xt}$$

Equation (4.23) & (4.24) are essentially the same (4.21) & (4.22), but $\alpha_i[y_{t-1} - \tilde{\beta}_1 x_{t-1} - \tilde{\beta}_0]$ has been replaced by $\hat{e}_{t-1}$ which simplifies the model estimation.

The term $\hat{e}_{t-1}$ is called the cointegration relationship and is an essential part of the cointegration analysis as it shows how variables affect changes in another variable on a long-term basis. Should the variables deviate from their long-run equilibrium then α_y and α_x will determine how fast the variables are corrected back to their long-run equilibrium. Thus the cointegration vector coefficients α_y and α_x tell how closely linked one or both of the prices are to each other on a long-term basis. The coefficients $a_{mj}(i)$ show how lags of changes (t-i) affect the change in period t, and are thus an indicator of short term effects on the dependent variable.

Notice that since the cointegration relationship is the estimated error term from equation (4.17), it means that the Engle-Granger procedure requires the researcher to condition on one of the two variables before starting performing any calculations. This has led to criticism of the method as it is not always intuitive which variable that should be the dependent variable.

When applying the ECM in statistical software, like e.g. Stata, it is often easier to estimate the ECM as a Vector Autoregressive Model (VAM). It is thus preferable to rewrite the model on a vector basis:

$$(4.25)\quad \begin{pmatrix} \Delta y_t \\ \Delta x_t \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \begin{pmatrix} \alpha_y\, \hat{e}_{t-1} \\ \alpha_x \hat{e}_{t-1} \end{pmatrix} + \sum_{i} \begin{pmatrix} \alpha_{11}(i) & \alpha_{12}(i) \\ \alpha_{21}(i) & \alpha_{22}(i) \end{pmatrix} \begin{pmatrix} \Delta y_{t-i} \\ \Delta x_{t-i} \end{pmatrix} + \begin{pmatrix} \varepsilon_{yt} \\ \varepsilon_{xt} \end{pmatrix}$$

Determining how many lags that should be included can be hard sometimes. There are therefore so-called selection criteria that might help.

Two common criteria used are the Akaike Information Criteria (AIC) and the Schwartz Bayesion Criterion (SBC). They are denoted in the following way (Enders 2010c):

$$(4.26)\quad \mathrm{AIC} = \mathrm{T}\ln(\mathrm{RSS}) + 2\mathrm{n}$$

$$(4.27)\quad \mathrm{SBC} = \mathrm{T}\ln(\mathrm{RSS}) + \mathrm{n} * \ln \mathrm{T}$$

Where n is the total number of parameters estimated and T is the total number of observations. To determine the appropriate lag length, estimate the AIC and the SBC for models with different amounts of lags, e.g. from zero to five lags. The model that obtains the lowest score will be the most fitting. Since the two criteria have a different construction, they will not always give the same conclusion. SBC will for example “always” prefer a model with the same or fewer lags than what AIC will do. Mathematically this can be shown in the following way:

$$\mathrm{AIC} < \mathrm{SBC}$$

$$\mathrm{T}\ln(\mathrm{RSS}) + 2\mathrm{n} < \mathrm{T}\ln(\mathrm{RSS}) + \mathrm{n} * \ln \mathrm{T}$$

$$2\mathrm{n} < \mathrm{n} * \ln \mathrm{T}$$

$$\mathrm{T} > \mathrm{e}^2 \approx 7{,}39 \approx 7$$

This means that for any given lag, the AIC will be smaller than SBC if there are more than seven observations. Since the preferred model is chosen based on the smallest criteria value, it means that the AIC will be tilted towards choosing models with more lags than what the SBC does. If the AIC and SBC choose the same model you can be pretty confident that you have the correct model specification. If they however should deviate, then the choice is a bit more uncertain. Since a more parsimonious model is always preferred over a more complicated one with equal properties, the best solution might be to estimate the model proposed by SBC and then check that the residuals are white noise. If they are not white noise, continue with the model proposed by the AIC, and again check the white noise condition for the residuals.

Step 4: Model diagnostics

Statistical assessment of model adequacy is important with any model, and the error-correction model is no exception. The first thing that should be done is checking whether the residuals are white noise or not. If they show evidence of autocorrelation then the lag length might be too short.

The next thing is to control that the speed of adjustment coefficients are statistically and economically significant. If. e.g. $\alpha_y = 0$ is it means that Δy_t is not affected by any deviations from the estimated long-run equilibrium. Further, if all a_{mj} is also zero than we can conclude that x_t does not Granger cause[12] y_t, meaning that changes in x_t do not precede changes in y_t.

4.2 Structural breaks

4.2.1 Stationary processes that appear non-stationary

Following Perron (1989), it is well known that apparent persistence in macroeconomic data could be the result of unmodeled structural breaks in the underlying data process. In the presence structural breaks, the various Dickey-Fuller test statistics are biased toward the nonrejection of a unit root. This means that a series can appear to be well-modeled as an I(1) process, but actually is a stationary process with one or several structural breaks. One way to test for unit roots in the presence of n structural break is to split the dataset in n+1 parts and test each of the data samples separately. However, it is often not easy spotting where structural breaks have taken place, and this method will also reduce the degrees of freedom and hence the rejection power of the test.

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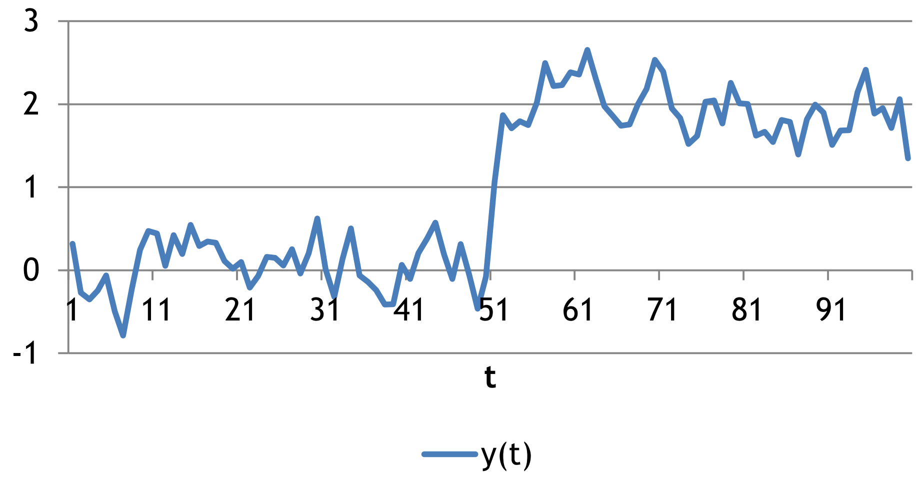
[12] Granger causality states that changes in one variable precede the changes in another variable, i.e. you do not have to make any assumptions about dependency between the variables.

Perron (1989) exemplified how important detecting structural breaks are by redoing Nelson and Plosser's (1982) work on macroeconomic variables. Contrary to Nelson and Plosser's findings Perron found that most of the economic time series were not characterized by a unit root, but trend stationary processes with one or several structural breaks.

One example of a stationary process that will be mistaken for a unit root is shown in the following figure (process simulated in the statistical software R):

Figure 4.3: $y_t = 0.5y_{t-1} + \varepsilon_t + D_L$



The time series exhibits a sudden jump at t=50, which is modeled by setting $D_L = \begin{cases} 1 \text{ if } t \geq 51 \\ 0 \text{ if } \leq 50 \end{cases}$.

4.2.2 Perron's test for unit roots in the presence of structural breaks

Perron (1989) went on to develop a test for structural breaks at time period $t = \tau + 1$. The main idea behind the test is as follows: You specify a null hypothesis where the process is a unit root and the change that you want to examine is modeled as an alteration to the unit root process. The alternative hypothesis states that the process does not contain a unit root, but a time trend and a lasting change in either the intercept or time trend, or both.

The test is highly flexible as you can choose to test any hypothesis specification as long as H_0 contains a unit root and H_1 a deterministic time trend. Here is one list of possible null and alternative hypothesis:

	Test structure	H_0	H_1
1	Pulse vs. constant change	$y_t = a_0 + y_{t-1} + \mu_1 D_P + \varepsilon_t$	$y_t = a_0 + a_2 t + \mu_2 D_L + \varepsilon_t$
2	Change in the unit root drift vs. change in the time trend	$y_t = a_0 + y_{t-1} + \mu_2 D_L + \varepsilon_t$	$y_t = a_0 + a_2 t + \mu_3 D_T + \varepsilon_t$
3	1 and 2 combined	$y_t = a_0 + y_{t-1} + \mu_1 D_P$ $+\mu_2 D_L + \varepsilon_t$	$y_t = a_0 + a_2 t + \mu_2 D_L$ $+\mu_3 D_T + \varepsilon_t$

Where D_P is a pulse dummy, i.e. $D_P = \begin{cases} z & \text{if } t = \tau + 1 \\ 0 & \text{otherwise} \end{cases}$

D_L is a level dummy, i.e. $D_L = \begin{cases} w & \text{if } t \geq \tau + 1 \\ 0 & \text{otherwise} \end{cases}$

D_T is a trend dummy, i.e. $D_T = \begin{cases} t - \tau & \text{if } t > \tau \\ 0 & \text{otherwise} \end{cases}.$

The three step test procedure will now be explained and exemplified using the “pulse vs. constant change” test specification (Enders 2010d).

Step 1: Detrending

Detrend the time series using the alternative hypothesis and call the residuals $\hat{y}_t$. Hence we have the following equation:

$$y_t = a_0 + a_2 t + \mu_2 D_L + \hat{y}_t$$

Step 2: Regress the residuals

Estimate the regression:

$$\hat{y}_t = a_1 \hat{y}_{t-1} + \varepsilon_t$$

Alternatively an augmented version of the test can be used if autocorrelated error terms are suspected:

$$\hat{y}_t = a_1\hat{y}_{t-1} + \sum_{i=1}^{k} \beta_i \Delta\hat{y}_{y-i} + \varepsilon_t$$

Step 3: Testing residuals

Calculate the t-statistics for the null hypothesis $a_1 = 1$ (null hypothesis is as before non-stationarity). The statistics are then compared to critical values calculated by Perron. It can be shown that the distribution of a_1 depends on the proportion of observations prior to the structural change. This proportion is denoted $\lambda = \tau/T$ where T is total number of observations. Perron's critical values will be equivalent to the Dickey-Fuller critical values for $\lambda = 0$ and $\lambda = 1$, but by definition there is no structural break here. For all other values the critical values will exceed the Dickey-Fuller critical values. Thus, if H_0 cannot be rejected with the Dickey-Fuller critical values in a Perron's test, then it cannot be rejected with the Perron critical values.

5 Empirical testing

5.1 The price series

The price data used in the empirical testing will be based on monthly frequency from January 1981 to December 2010. This is a much longer data series than what is used in similar research (e.g. Tveteraas 2000 and Anderson & Kristoffersson 2004). Since the data series covers when aquaculture consumed very little fishmeal all the way up to when it is the most significant consumer, it will enable thorough testing of the cointegration relationship and possible structural breaks. The fishmeal price series (hereafter denoted fm_t) is 64/65 percent protein meal from any origin traded at the Hamburg exchange. 64/65 percent meal is widely used in both aquaculture and terrestrial production, and should therefore be a good proxy for fishmeal. The soybean meal price series (hereafter denoted sm_t) is 44 percent protein meal from any origin traded at either Rotterdam or Hamburg. This soybean meal is traded frequently and known to be used both in aquaculture and agriculture and should therefore fit the analysis. Both fm_t and sm_t are quoted in US Dollar per ton. The data from 1981 – 2008 are provided by Globefish[13] (2009) and the remaining two years are data obtained from the International Monetary Fund's statistical database (IMF 2011). The price series are presented in figure 5.1 and descriptive statistics in table 5.1.

From 1981 to 1995 the fishmeal price fluctuated around USD 400/ton while soybean meal prices remained more stable around USD 200/ton. From 1995 the variance in the fishmeal price appears to increase and there is a clear upward trend from about 2000. Soybean meal has however remained more stable in the corresponding period, with a price hike from 2006 to 2008.

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[13] Globefish is a subdivision of the United Nations' Food and Agricultural Organization

Figure 5.1: Fishmeal and soybean meal price series (Globefish 2009 and IMF 2011)

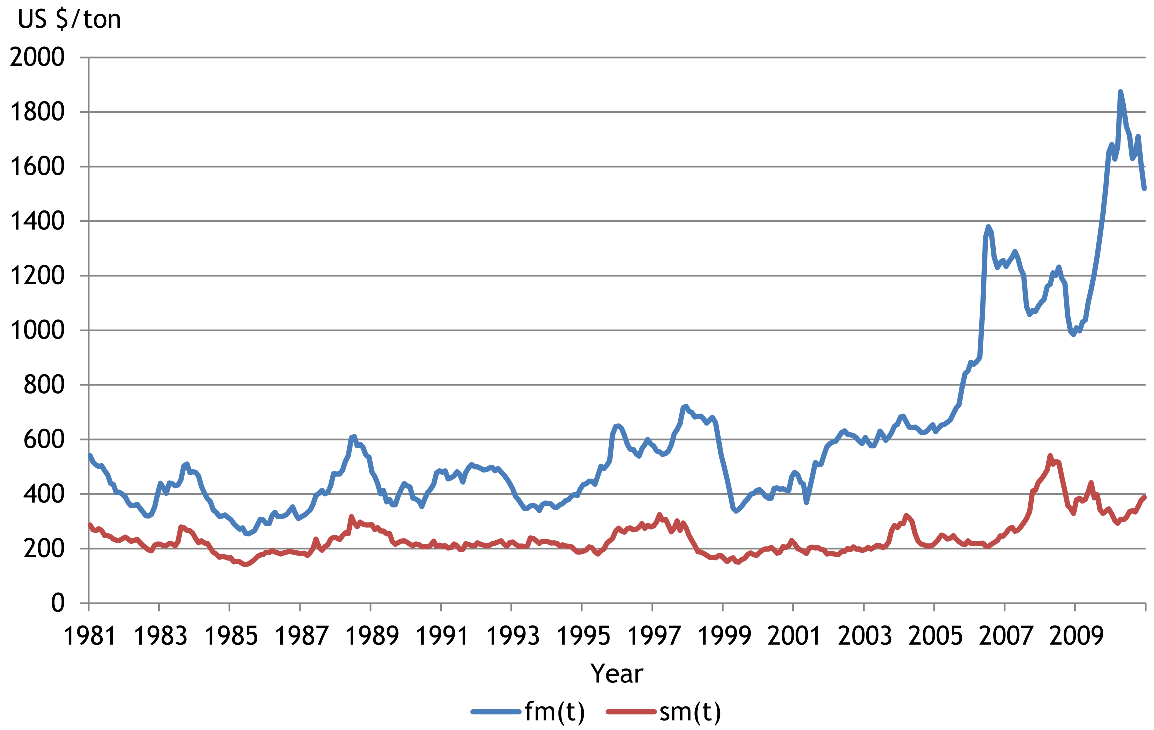


Table 5.1: Descriptive statistics 1981 - 2010

Variable	# Obs.	Mean	Std.dev.	Min	Max
fm_t	360	609	334	254	1874
sm_t	360	239	67	141	541

Simple visual examination is seldom enough to conclude that two variables are cointegrated, but figure 5.1 gives an indication that the fishmeal and soybean meal price might share some stochastic similarities. Especially in the period 1981 to 2001 the two variables movement seem to coincide. After 2001 the price seam to diverge somewhat. The fishmeal-soybean meal ratio might shed some more light on the possible price relationship.

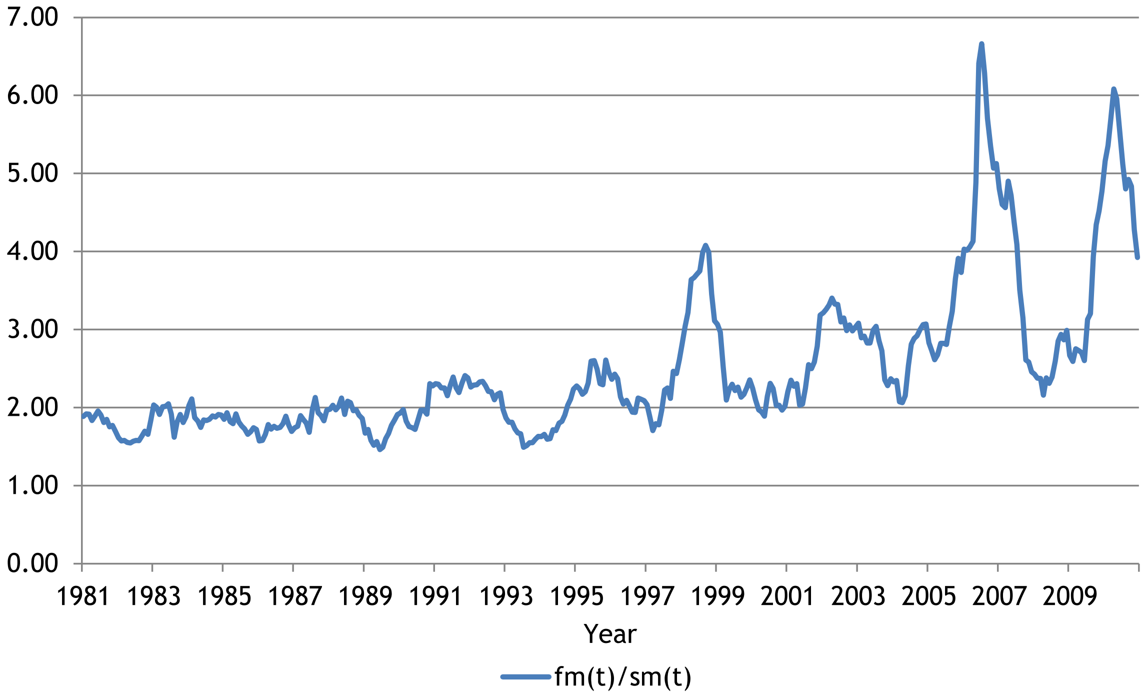
5.1.1 The fishmeal-soybean meal ratio

The fishmeal-soybean meal ratio is a figure that has been extensively used by practitioners and feed producers. The number is calculated by dividing the fishmeal price by the soybean meal price, i.e. fm_t/sm_t. The logic behind the ratio is that if fishmeal and soybean meal are priced mainly from their level of protein (fishmeal's 65 percent vs. soybean meal's 44 percent), than their price relationship should reflect this. If you believe that fishmeal and soymeal are priced exclusively because of protein, then the long term price relationship should be

$$65/44 \approx 1.5$$

By feed mill producers and traders it is more common that a ratio of about 2 is assumed to be fair, which probably incorporates that fishmeal has other beneficial properties besides a high protein level compared to soybean meal.

Figure 5.2: Fishmeal-soybean meal price ratio



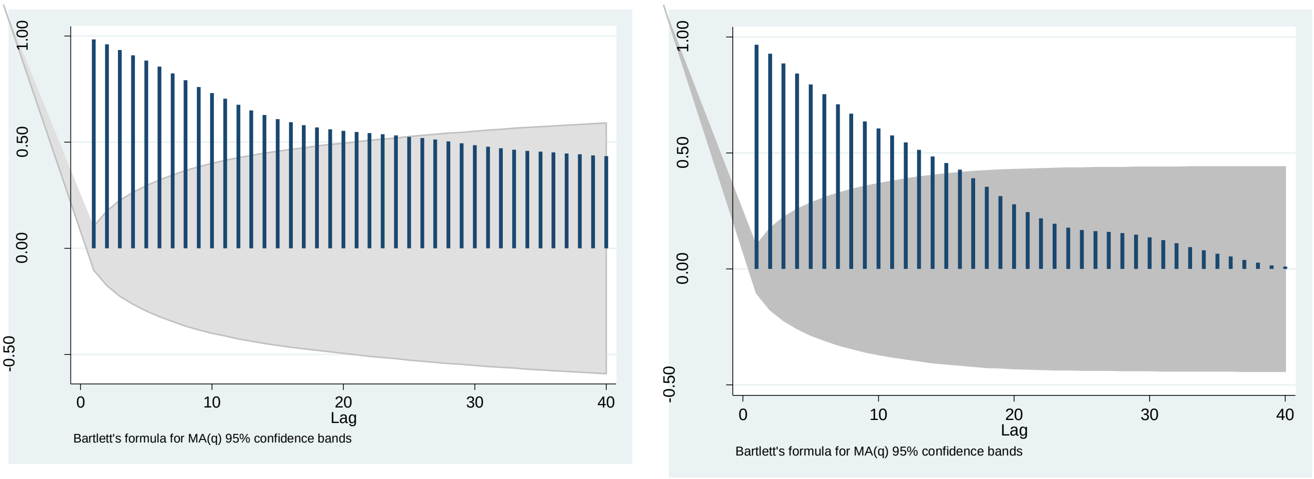
The price ratio is illustrated in figure 5.2. From 1981 to roughly 1997 one cannot say that the price relationship appears to be very different from 1.5 - 2 on the long-term. There are short-term deviations north of this, but the relationship seems to converge back. An interpretation of this is that feed producers, who try to minimize their production cost, will alter their purchasing quantities of fishmeal and soybean meal according to the relative price. Thus a long run equilibrium relationship is established at the price ratio where the average feed producer finds the ratio acceptable, and any deviations from this ratio will cause alternation of future fishmeal and soybean meal orders by feed producers.

In 1997 the ratio had a big jump which coincided with an El Niño that caused havoc on South American fisheries and lowered world fishmeal output. After 1997 the ratio seemed to behave more erratically at a level above 1.5. It appears therefore that the price series display a closer relationship from 1981 to 1997 than from 1997 to 2010, which could indicate that one or several structural breaks have taken place. Kristofersson & Anderson (2004) performed a study on the fishmeal – soybean meal relationship using optimal hedge ratios to discover breaks. They found evidence of possible structural breaks in 1988, 1995 and 1996. The confidence bands of the test were however quite wide (5 to 8 years), so pinpointing an exact break is not trivial. In my studies, I will control for a possible structural break in 1997.

5.1.2 Autocorrelation plots

The Dickey-Fuller test is an important part of the forthcoming cointegration analysis, and as mentioned it might be preferable to use the Augmented Dickey-Fuller test to clear up any autocorrelation. Autocorrelation plots can help decide if the series are non-stationary or not as a high degree of autocorrelation would suggest non-stationarity.

Figure 5.3: Autocorrelation plots fm_t and sm_t

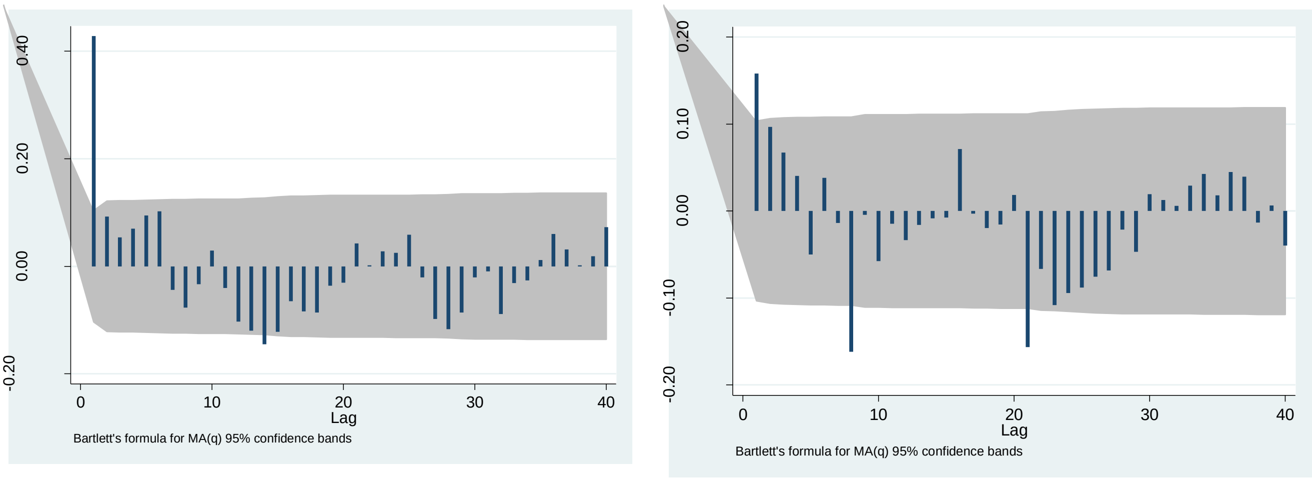

Fishmeal autocorrelation plot

Soybean meal autocorrelation plot

The grey bands show the 95 percent confidence level, i.e. if spikes are outside the grey area the null of no autocorrelation is rejected. Both autocorrelation plots exhibits strong evidence of autocorrelation, and thus the series appear to be non-stationary.

Figure 5.4 shows the autocorrelation plot for the differenced variables (i. e. $\Delta x_t = x_t - x_{t-1}$), and there is here no clear indication of autocorrelation. The differenced variables may then be stationary and thus the variables themselves are I(1) process. However, a more formal test is in order before this can be established. Since the differenced variable show no clear signs of autocorrelation, it could be superfluous to perform an augmented version of the unit root test. As mentioned in section 4.1.2.2, including irrelevant lags of the variable will lower the test's rejection power and hence cause a wrongful acceptance of a process as non-stationary more often. Having the ACP-plots in mind though, I don't think this will be a problem with this data. I will therefore use an augmented test and find the correct lag length with the procedure by finding the last significant lag like described in section 4.1.2.3. Should there be any problems with weak test results more formal tests for autocorrelation can be performed in order to establish if the augmented test structure is appropriate.

Figure 5.4: Autocorrelation plots for differenced variables, Δfm_t and Δsm_t


Fishmeal autocorrelation plot

Soybean meal autocorrelation plot

5.2 Cointegration analysis

As mentioned in section 4, cointegration analysis enables us to test whether two variables share stochastic similarities so that a linear difference of them will be stationary. More practically this means that if it can be proven that fishmeal and soybean meal are cointegrated, it is evidence that there is some sort of mechanism linking them together in the long-term. This linkage implies that prices cannot drift too far apart in the long-term, and should a shock cause these prices to drift apart, a correction mechanism called the cointegration relationship will bring them back to their long-term relationship. It should be mentioned that if it is not possible to prove that the price series are cointegrated, it is still not evidence that the markets are independent. There might be integration links that cointegration analysis does not pick up.

Stata (version 11.1) will be used for all test procedures. Firstly, the dataset for the whole period will be tested. Afterwards the price series will be divided in different periods which enables a comparison of the cointegration relationship in the different periods.

5.2.1 Testing for the whole period: 1981 – 2010

Step 1: Checking if the price series contain a unit root

First, a test for unit root needs to be performed in order to determine if both variables are I(1). Since the fishmeal price displays a possible change in the time trend and a corresponding structural break around 1997 (see figure 5.1), I will use a Perron's test that takes this into account. More precisely, I will control that there is a change in the unit root drift vs. a change in the time trend (i.e. equal to the second specification in section 4.2.2). For fishmeal I thus have the following hypothesis:

(5.1) $H_0: fm_t = a_0 + fm_{t-1} + \mu_2 D_L + \varepsilon_t$

(5.2) $H_1: fm_t = a_0 + a_2 t + \mu_3 D_T + \varepsilon_t$

I estimate the regression

(5.3) $fm_t = a_0 + a_2 t + \mu_3 D_T + \widehat{fm}_t$

Where $D_T = \begin{cases} t - 192 & \text{if } t > 192 \\ 0 \text{ otherwise} & \end{cases}$.

The trend dummy is set at $t - 192$ because there are 192 observations before 01.1997, and the dummy will then exhibit a linear trend after this point. The regression of this equation yields the following statistics:

Table 5.2: Regression for Perron's test fm_t

Indep. variable	Coeff.	t-statistics	p-value
a_2	-0.35	-1.82	0.07
μ_3	5.49	16.03	~0
Constant	424	17.89	~0
$R^2 = 0.75$			

The estimated residuals are then stored and the following regression is run:

(5.4) $\widehat{fm}_t = a_0 \widehat{fm}_{t-1} + \varepsilon_t$

Output:

Table 5.3: Perrron's test fm_t

Indep. variable	Coeff.	Std.err.	t-stat
$\widehat{fm}_{t-1}$	0.98	0.011	-1.82
$R^2 = 0.96$			

Residuals from this regression are tested and show no signs of autocorrelation. The generated t-stat is here for the hypothesis that $a_0 = 1$. This t-stat is within the critical values of the Dickey-Fuller test (cf. table 4.1) and there is thus no point in simulating the correct Perron critical values (Perron's critical values are always stricter than the Dickey-Fuller). The null hypothesis of a unit root is thus not rejected, and we can conclude that the fishmeal price series is non-stationary. Whether it is integrated of a higher order than one will be tested further down the analysis.

The soybean meal equation exhibits no clear indication of a similar trend or break, and I will therefore test this with a Dickey-Fuller without a trend term. I will use the augmented test to prevent any autocorrelation from distorting my results. I thus run the following regression, and the lag-length is decided by starting out with ten lags and reducing them until the last lag is statistical significant:

$$(5.5)\quad \Delta sm_t = \alpha + \theta sm_{t-1} + \sum_{k=2}^{p} \beta_k \Delta sm_{t-k+1} + e_t$$

The corresponding hypotheses are:

$H_0: \theta = 0$ (the series is not stationary)

$H_0: \theta < 0$ (the series is (asymptotic)stationary)

Stata yields the following output:

Table 5.4: Dickey-Fuller test $\mathrm{sm_t}$

Variable	# lags	t-statistics	5% c.v.[14]	10% c.v.
$\mathrm{sm_t}$	4	-2.28	-2.86	-2.57

The null hypothesis is not rejected and it can thus not be rejected that the series is non-stationary.

To check that both variables are in fact I(1) and not integrated of any higher order I differentiate the variables and run the Dickey-Fuller test on the differentiated variables. I.e. I calculate the following new variables:

$$(5.6)\quad \Delta \mathrm{fm_t} = \mathrm{fm_t} - \mathrm{fm}_{\mathrm{t_{t-1}}}$$

$$(5.7)\quad \Delta \mathrm{sm_t} = \mathrm{sm_t} - \mathrm{sm}_{\mathrm{t_{t-1}}}$$

Given the initial non-stationary test structures, $\Delta \mathrm{fm_t}$ will be tested with a drift and time trend, while $\Delta \mathrm{sm_t}$ will be tested with only a drift term[15].

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[14] c.v.=critical value

[15] Proof for new test structures: Initially the fishmeal price is given by the following equation

$$\mathrm{fm_t} = \beta_0 + \rho \mathrm{t} + \beta_1 \mathrm{fm_{t-1}} + \mathrm{e_t}$$

Where β_0 is a constant term, t the time trend, $\mathrm{x_t}$ the independent variable and $\mathrm{e_t}$ the error term. When the equation is differentiated we get:

$$\mathrm{fm_t} - \mathrm{fm_{t-1}} = \beta_0 + \rho \mathrm{t} + (\beta_1 - 1)\mathrm{fm_{t-1}} + \mathrm{e_t}$$

And there is still a time trend and a constant term in the differentiated equation. This proof can be extended to the soybean meal test structure.

I obtain the following t-statistics:

Table 5.5: Unit root test for differenced variables

Variable	# lags	t-statistics	5% c.v.	10% c.v.
Δfm_t	6	-6.51	-3.41	-3.12
Δsm_t	7	-7.31	-2.86	-2.57

Both t-statistics are well below the critical values and the null hypothesis of non-stationarity is thus rejected, and it can be concluded that the variables are integrated of order 1.

Step 2: Estimating the long-run relationship

Step 1 showed that both variables are unit roots, so the long-run relationship can now be estimated. Since the production and trade of soybean meal is over 10 and 25 times respectively that of fishmeal (cf. discussions in chapter 2), it is likely that soybean meal prices will affect fishmeal prices more significantly than vice versa. The fishmeal price appears therefore as the natural choice as the dependent variable. However, Durand (1994) showed that the fishmeal price change might have an influence on the soybean meal price. On the other hand, the results should theoretically not depend on which variable you choose as dependent so I continue with my test specification.

Next the right-hand side of the equation must be determined. The fishmeal price exhibits an upward trend so you could argue that the model should include a time trend. This might be reasonable since aquaculture has become a more significant player over the time period and thus their increased demand has driven prices upwards. Including a deterministic trend term prior to 1997 might however be superflous as the fishmeal-soybean meal ratio (cf. figure 5.2) does not exhibit any upward trend prior to 1997. Thus any increase in the fishmeal price before this point will be captured by the soybean meal coefficient in the regression. As mentioned in section 2.1.3, in 1997 one of the strongest El Niños of modern time occurred. The increased water temperatures and the reduced upwelling had a severe negative effect on fish stocks, particularly in South America, and world production level was reduced by 22 percent over a two year period. While South American producers suffered from the reduced harvest, other countries thrived on the increasing prices. The shift in the in the fishmeal price at this point could be modeled with a time dummy variable like the one used in the Perron test in section 5.2.1. The model would then be the following:

$$(5.8)\quad \mathrm{fm_t} = \beta_0 + \beta_1 \mathrm{sm_t} + \mu_3 \mathrm{D_T} + \mathrm{e_t}$$

Another alternative is to use a simple dummy variable and model a possible shift as a change in the soybean meal coefficient. This model would then be:

$$(5.9)\quad \mathrm{fm_t} = \beta_0 + (\beta_1 + \mathrm{D_L}\beta_2)\mathrm{sm_t} + \mathrm{e_t}$$

Where $\mathrm{D_L} = \begin{cases} 1 \text{ for time} \geq 1997 \\ 0 \text{ otherwise} \end{cases}$

This approach will provide basic information about how the price relationship between fishmeal and soybean meal has changed, which is what this paper is trying to examine. It will also utilize specific price information and not just a deterministic time trend like equation (5.8). The problem with this specification though, is that the possible structural break around 1997 is more gradual than sudden. From figure 5.2 we can see that the ratio has a more erratic upward going trend and thus a single extra soybean meal coefficient from 1997 will not take this adequately into account. Even though equation (5.9) offers appealing properties, I will continue with equation (5.8) because it will probably model the structural change better.

Output result from regression of (5.8) (original table shown in appendix Table A.1)

Table 5.6: Estimating the long-run relationship

Indep. var.	Coef.	t-stat.	p-value	[95% conf. interval]	
Constant	145	4.51	~0.00	82	209
Soybean meal (β_1)	1.19	8.14	~0.00	0.9	1.47
Trend dummy ($\mathrm{D_T}$)	4.56	25	~0.00	4.2	4.92

The soybean meal coefficient (β_1) is called the cointegrating coefficient, and thus an estimate of the price ratio $\mathrm{FM_t/SM_t}$ that drives the behavior of prices in these markets. The cointegration coefficient is estimated at 1.19 which is a bit below what one would expect the price ratio to be if fishmeal and soybean meal was priced exclusively for their protein content[16]. The trend dummy variable is estimated at 4.56 and it illustrates the high price growth that fishmeal has had from 1997 – 2010.

The analysis is continued by obtaining the estimated residuals $\hat{e}_t$. The residuals are then differentiated and regressed on the lagged residual terms. I.e.

$$(5.10)\quad \Delta\hat{e}_t = a_1\hat{e}_{t-1} + \sum_{i=1}^{n} a_i\, \Delta\hat{e}_{t-i} + \varepsilon_t$$

This regression yields the following results (critical values incorporate the fact that $\hat{e}_t$ contains estimated coefficients, original table shown in appendix table A.2):

Table 5.7: Testing for cointegration

Variable	# lags	t-statistics	5% c.v.	10% c.v.
$\hat{e}_t$	6	-5.13	-3.78	-3.50

The t-statistic is below the critical values and that implies that the null hypothesis that the variables are not cointegrated can be rejected– i.e. the variables are cointegrated. There is thus evidence of an equilibrium relationship, which means that a specific value of the fishmeal-soybean meal price ratio drives the price behavior in the markets.

<u>Step 3: Estimating the error-correction model (ECM)</u>

Since it is concluded that fm_t and sm_t are $CI(1,1)$ the error-correction model (ECM) can be estimated.

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[16] The coefficients of the estimated regression will be super consistent, but one should be cautious about interpreting the t-statistics from this regression as they will not have an asymptotic t-distribution. This is because the errors are autocorrelated.

Remember the cointegration relationship is now given by the lagged estimated residual term which was calculated to be

$$(5.11)\quad \hat{e}_{t-1} = fm_{t-1} - 145 - 1.19sm_{t-1} - 4.56D_T$$

The ECM on vector form is then as follows:

$$(5.12)\quad \begin{pmatrix} \Delta fm_t \\ \Delta sm_t \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \begin{pmatrix} \alpha_{fm}\hat{e}_{t-1} \\ \alpha_{sm}\hat{e}_{t-1} \end{pmatrix} + \sum_i \begin{pmatrix} \alpha_{11}(i) & \alpha_{12}(i) \\ \alpha_{21}(i) & \alpha_{22}(i) \end{pmatrix} \begin{pmatrix} \Delta fm_{t-i} \\ \Delta sm_{t-i} \end{pmatrix} + \begin{pmatrix} \varepsilon_{fmt} \\ \varepsilon_{smt} \end{pmatrix}$$

To determine the appropriate lag length I use the AIC and the SBC criteria, and Stata produces the following statistics (original tables shown in appendix Table A.3):

Table 5.8: Selection criteria

	Δfm_t		Δsm_t	
Lag	AIC	SBC	AIC	SBC
0	9.955	9.966	8.274	8.285
1	9.754	**9.776**	8.255	**8.276**
2	**9.748**	9.781	**8.254**	8.287
3	9.750	9.794	8.258	8.302
4	9.754	9.809	8.263	8.318
5	9.755	9.821	8.264	8.330

Lowest value indicated by bold caption.

For fishmeal the AIC suggests a model with two lags, while SBC suggests one lag. As explained earlier it is expected that the SBC will suggest a more parsimonious model. For soybean meal the result is the same: AIC suggest a model with two lags while the SBC suggests one lag. Since the selection tests suggest different models the correct amount of lags are a bit ambiguous. Since a more parsimonious model is always preferred over a more complicated model if they have equal properties, I will proceed using a model with one lag and then test if the residuals appear to be white noise. Should they appear to not be white noise I will proceed with a two lag model.

A Vector Autoregressive Model (VAR) is then estimated in Stata with a lag length of 1. The VAR specification yields the following result (original table shown in appendix Table A.4):

Table 5.9: Vector Error-Correction Model (VECM)

Variable	Coeff.	Std. Err.	t-stat.	p-value	95% C.I.	
Δfm_t						
Δfm_{t-1}	0.45	0.048	9.44	~0.000	0.36	0.55
Δsm_{t-1}	-0.003	0.110	-0.02	0.982	-0.22	0.21
$\hat{e}_{t-1}$	-0.037	0.011	-3.38	0.001	-0.059	-0.016
Constant	1.42	1.64	0.87	0.39	-1.79	4.64
Δsm_t						
Δfm_{t-1}	-0.028	0.023	-1.21	0.23	-0.073	0.017
Δsm_{t-1}	0.17	0.053	3.24	0.001	0.067	0.273
$\hat{e}_{t-1}$	0.006	0.005	1.15	0.25	-0.004	0.016
Constant	0.374	0.787	0.48	0.63	-1.17	1.92
Residual autocorrelation test						
Lag	Chi	P-value				
ε_{fmt}	7.68	0.11				
ε_{smt}	8.7	0.07				
H_0: no autocorrelation						

As stated earlier, $\hat{e}_{t-1}$ will indicate long-run effects and the lagged variables of Δfm_t and Δsm_t short term effects. The VECM show that errors around the long-term have a significant (negative) influence on fishmeal prices, but not on soybean meal prices. For fishmeal this means that any deviation away from the equilibrium will over time be corrected back towards the long-run relationship. The soybean meal price does not exhibit any short term effects (shown by Δsm_{t-1}) on the fishmeal price. There might be a weak indication that fishmeal affects soybean meal price long- or short term, but the corresponding p-values of 0.25 and 0.23 is not near to be conclusive evidence of that.

I will revisit these numbers for further discussion when all test results are obtained. Next, I will split my dataset and see how the growth in the aquaculture sector has altered the co-integration relationship between fishmeal and soybean meal.

5.2.2 Testing parts of the data

The previous section showed that when correcting for a possible structural break around 1997, fm_t and sm_t are cointegrated. However, within this 30 year period there have been significant changes in consumer structure and output level of fishmeal, and it is thus interesting to see how the cointegration might have changed. There is one downside of approaching this problem in such a manner, as splitting the data reduces the degrees of freedom and thus lowers the test power. However, the potential insight in the cointegration development makes it a worthwhile exercise.

I will split the dataset in three periods. The first will range from the start (1981) until 1988 as in this period aquaculture was a small consumer of fishmeal. From 1989 up till 1998 the aquaculture industry expanded from consuming 12 to 48 percent of global fishmeal production. The second period from 1989 – 1998 will thus be interesting as it will shed light on how this rapid expansion has altered the price relationship. The third and last period will be 1999 – 2010 which is characterized by increasing fishmeal prices and a continuing high fishmeal consumption by the aquaculture sector. As with the test for the whole period, I will include a trend dummy variable from 01.1997 up to 12.2010.

As I have already described the Engle-Granger four-step procedure both theoretically and practically, I will not go through it again for these time series.

The Dickey-Fuller test results for unit roots are the following:

Table 5.10: Dickey – Fuller tests for unit roots

Var.	Time period	Test	Lags	t-stat.	5%c.v.
fm_t	1981 - 1988	DF with const., no trend	1	-1.55	-2.86
Δfm_t	1981 - 1988	DF with const., no trend	1	-5.76	-2.86
sm_t	1981 - 1988	DF with const., no trend	0	-1.6	-2.86
Δsm_t	1981 - 1988	DF with const., no trend	0	-9.35	-2.86
fm_t	1989 – 1998	DF with const., no trend	1	-1.84	-2.86
Δfm_t	1989 – 1998	DF with const., no trend	0	-6.66	-2.86
sm_t	1989 – 1998	DF with const., no trend	6	-2.56	-2.86
Δsm_t	1989 – 1998	DF with const., no trend	5	-3.48	-2.86
fm_t	1999 - 2010	DF with const. and trend	2	-2.96	-3.41
Δfm_t	1999 - 2010	DF with const. and trend	1	-7.17	-3.41
sm_t	1999 - 2010	DF with const. and trend	1	-2.58	-3.41
Δsm_t	1999 - 2010	DF with const. and trend	0	-9.2	-3.41

All variables are considered non-stationary at a 5 percent level, while none of the differenced variables show signs of non-stationarity. Boarder cases might be sm_t in the time period 1989 – 1998 and fm_t in the time period 1999 – 2010. The test criteria is still fulfilled at a 5 percent level and I will continue with the assumption that all variables are I(1) and eligible for cointegration testing. The three long-run relationship equations are then as follows:

$$(5.12)\quad 1981-1988\text{: } fm_t = \beta_0 + \beta_1 sm_t + e_t$$

$$(5.13)\quad 1989-1998\text{: } fm_t = \beta_0 + \beta_1 sm_t + \mu_3 D_T^1 + e_t$$

$$(5.14)\quad 1999-2010\text{: } fm_t = \beta_0 + \beta_1 sm_t + \mu_4 D_T^2 + e_t$$

Where $D_T^1 = \begin{cases} t-192 & \text{if } t \geq 193 \\ 0 \text{ otherwise} \end{cases}$ and $D_T^2 = \begin{cases} t-216 & \text{if } t \geq 216 \\ 0 \text{ otherwise} \end{cases}$.

Observation t=193 corresponds to 01.1997 while t=216 is 01.1999.

The cointegration test statistics and corresponding VECMs (Vector Error Correction Models) are as follows (VECM original tables shown in appendix Table A.5 and A.6):

Table 5.11: Cointegration tests and estimation of VECMs

Period	Coint. t-stat	Fishmeal				Soybean meal			
		Const	Error	Δfm_{t-1}	Δsm_{t-1}	Const	Error	Δfm_{t-1}	Δsm_{t-1}
1981 - 1988	-4.03***	0.17	-0.023	0.23**	0.51***	0.17	0.13***	-0.04	0.16
1989 - 1998	1.14	-	-	-	-	-	-	-	-
1999 – 2010	-3.53*	1.8	-0.049**	0.46***	-0.03	1.72	0.008	-0.04	0.25***

*=10% significance **=5% significance ***=1% significance

For the first period (1981 – 1988) the cointegration test gives clear evidence that variables are cointegrated. The VECM show that the error term is non-significant for fishmeal (-0.023), meaning there that there is no long-run relationship between fishmeal and soybean meal that affects future fishmeal price changes. Fishmeal is however significantly and positively influenced by previous price changes in both fishmeal (0.23**) and soybean meal (0.51***). So in the short term, fishmeal price change will be influenced by price changes in soybean meal. Surprisingly, the estimation shows that soybean meal is linked to a long-run relationship to the fishmeal price (-0.049**). This is a bit contrary to what one might think, considering the vast size of the soybean meal market compared to the fishmeal market. These results are however consistent with work done by Durand in her paper on fishmeal price behavior (1994). She performed an Engle-Granger test on Hamburg fishmeal and soybean meal price series from January 1977 to June 1993 and found that the fishmeal price affects the soybean meal price in both the long- and short run, while soybean meal only affects fishmeal prices in the short run.

The second period 1989 – 1998 was chosen based on a hypothesis that the rapid growth in aquaculture fishmeal consumption might have altered the relationship amongst fishmeal and soybean meal. The cointegration statistics show that the price series exhibit no close relationship during this period. To be completely sure that a test misspecification is not causing the apparent break in the relationship, I have performed a test where a time trend is included for the whole period (result not shown). This does not alter the conclusion that fishmeal and soybean meal are not cointegrated during this period. The hypothesis that the growth in the aquaculture sector has delinked fishmeal and soybean meal markets might therefore not be far off, but one should keep in mind that there are several other factors that could have deteriorated this linkage. Anderson and Kristoffersson (2004) examined the period 1988 – 1996 using both the Johansen and the Engle-Granger cointegration methodology and they too found no evidence of a cointegration relationship during this period. Tveteraas (2000) however found strong evidence of cointegration between fishmeal and soybean meal during the period January 1986 to June 1997, by using the Johansen approach. This contradicts my findings and possible reasons might be different choice of methodology, slight differences in time interval and/or alternate model specifications. A possible explanation could be that the 1997 El Niño distorts my test results. If I set the time period in my dataset to the same as Tveteraas, I find stronger evidence for cointegration, but still not significant at a 10 percent level (results not shown).

From 1999 to 2010 fishmeal prices ranged from USD 337/ton (05.1999) to USD 1874/ton (05.2010), which is a difference of 456 percent. Soybean meal prices however spanned only from USD 150/ton (06.1999) to USD 541/ton (04.2008), which is a difference of 261 percent. This indicates that something has happened to the price relationship and you may be led to believe that the cointegration relationship has deteriorated even further from the last period. But when the time trend in fishmeal price is accounted for the cointegration test does actually support that the price series are cointegrated, as the p-value is close to 5 percent (-3.53*). One argument against this estimation could be the commodity boom pre-financial crisis 2008. From 2005 – 2008 most major commodities, including fishmeal and soybean meal, experienced a rapid price increase (commodity prices shown in appendix Figure A.2). This period's increase and turbulent price movements could therefore create an impression that fishmeal and soybean meal are cointegrated, when in fact they are just driven by another force simultaneously. However, if the data series is limited to 1999 – 2005, the analysis still give evidence of cointegration on a 10 percent level (cointegration analysis for the period 1999 – 2005 shown in appendix table A.7, A.8 and A.9). There is thus evidence, although not very strong, of a cointegration relationship between fishmeal and soybean meal in the period 1999 – 2010.

This is an interesting result, because when you look at the fishmeal – soybean meal ratio (cf. figure 5.2) for 1999 to 2010, one might be led to believe this is the period where the variables are the least linked. The analysis does in some sense also state this, as the variables are only cointegrated when the inherent trend in the fishmeal price is taken into account (results not provided here show that a cointegration relationship cannot be established unless a time trend is included). Thus, fishmeal and soybean meal have be de-linked in the manner that the fishmeal – soybean meal ratio has increased, but trend-adjusted fishmeal price changes are still influenced by the movements in the soybean meal price.

The estimated VECM for 1999 – 2010 shows that the fishmeal price is linked to a long-run equilibrium and deviations from this equilibrium will be corrected back over time (-0.049**). Fishmeal is also in the short run influenced by prior movements in the fishmeal price (0.46***), but not by changes in the soybean meal price. Soybean meal does not appear to share the same long-run link as fishmeal does (0.008), but is influenced in the short-run by changes in the soybean meal price (0.25***).

5.2.3 Comparison and interpretation of results

The statistical analysis for the period 1981 – 2010 showed that fishmeal and soybean meal have been cointegrated variables, where fishmeal is in the long-run linked to the soybean meal price, while soybean meal is not influenced by fishmeal. When the dataset was divided in three periods the analysis showed that the variables were cointegrated in the period 1981 – 1988, but this relationship broke down in the following period 1989 – 1998. From 1999 – 2010 there was some indication of a cointegrating relationship, however this link was only apparent when the trend in the fishmeal price was accounted for and only at a 10 percent significance level.

Even though the individual test conclusions were a bit unclear the trend in the data is apparent: The cointegrating relationship between soybean meal and fishmeal appears to weaken over the period. They started out as closely linked variables, then their relationship broke down and in the third period fishmeal prices soared without any similar reaction in the soybean meal prices. The analysis tells us that the fishmeal price still is influenced by the soybean meal price, but only when the upward trend is accounted for. In practical terms this means that there are some characteristics of the fishmeal besides protein that makes it valuable for some feed producers.

Furthermore, the upward trend in the fishmeal-soybean meal ratio tells us that relatively more and more quantity is demanded from producers that value these characteristics highly, i.e. aquaculture producers. But since the analysis shows that fishmeal still has a long-run relationship to the soybean meal, it means that feed producers are not blindly including a fixed amount of fishmeal in their feed diets. It is likely that each extra percentage of fishmeal included has a decreasing marginal utility. Thus when prices of fishmeal increase relative to soybean meal, producers switch some of the fishmeal to soybean meal (or other, cheaper meals). Conversely, as less and less fishmeal is included, the marginal cost of discarding one extra percentage of fishmeal in the diet increases, and thus the producers are ready to bid up the price of fishmeal.

The evidence points in the direction that a limited availability of fishmeal already has affected the profit of aquaculture production, and probably made some potential aquaculture production facilities not worthwhile investments. It is therefore tempting to conclude that the restrained fishmeal production will hamper the output of aquaculture in the future. The price of fishmeal will be bid up to a point where aquaculture production is the sole consumer of fishmeal. All capital cost adjusted profits from aquaculture production will be captured by fishmeal producers and aquaculture production is halted at some level.

This hypothesis does however rely on one crucial assumption: That there will be no technological development in feed diet structure and/or development of alternative raw material sources that can duplicate the non-protein characteristics that fishmeal is valued for. The next section will discuss whether such technological development is possible or not.

6 Research on alternative raw materials

As mentioned in the introduction and proved through the statistical analysis, fishmeal is valued by aquaculture producers not only for its protein. Other appreciated factors include an ideal amino acid profile, high digestibility, lack of anti-nutritional factors and a high palatability. In the search for viable alternative feedstuffs to fishmeal for aquafeeds, candidate ingredients must possess one or several of the mentioned characteristics, in addition to wide availability, competitive price, as well as ease of handling, shipping storage and use in feed production (Gatlin et al. 2007). This section will explore some of the main approaches that will (partly) fulfill these conditions and what challenges that must be overcome if they could be a valid alternative to fishmeal.

6.1 Intensify the use of vegetable proteins

As fishmeal prices have increased, there has been a trend towards replacing fishmeal with alternate sources and in particular vegetable plant material (e.g. soybean meal, canola meal, corn meal, etc.). Compared to fishmeal, these products are believed to be in abundance at a more reasonable price. Soybean meal production is for example 25 times the fishmeal production, while prices are currently (year 2011) about a quarter. However, replacing fishmeal with these substitutes is not straightforward.

Table 6.1, reproduced from FAO's paper "Impact of rising feed ingredient prices on aquafeeds and aquaculture production" (Rana et al. 2009), summarizes the product advantages and disadvantages in fishmeal substitution. Overall, the main advantage is a high content of proteins, and some of the plant materials have also shown to be highly digestible for carnivorous fish species. There are however serious drawbacks of using plant materials instead of fishmeal, including a lower level of Omega-3 acids and anti-nutritional factors. Anti-nutritional factors are substances which reduce an organisms' growth and hence it will extend the time it takes for a fish to reach mature age. On a general basis, their presence in *untreated* foodstuff results in anorexia and poor food conversion when used at high dietary concentrations. The presence of endogenous anti-nutritional factors within plant feedstuffs is believed to be the largest single factor limiting their use within compounded animal and fish feeds at high dietary levels (Tacon 1985).

Table 6.1: Advantages and disadvantages of plant substitutes for fishmeal (Rana et al. 2009)

Plant substitute	Advantages	Disadvantages
Soybean meal (SBM)	Economical and nutritious with high crude protein (44–48%) Cystine in higher concentration	Concentrations of the 10 essential amino acids (EAA) (lysine, methionine, cystine and threonine may be limiting) and tyrosine are lower; crude fat and ash content is lower but can be overcome with supplementation; high in non – starch polysaccharides; reduced feed intake; growth and development of intestinal enteritis; presence of anti–nutritional factors such as lectin; low in available phosphorous
Soybean protein concentrate (SPC)	EAA concentration matches or more to EAA concentrations in fishmeal	Methionine, cystine may be limiting; not economical for large scale use; crude fat and ash content is lower but can be overcome with supplementation
Soy protein isolate (SPI)	EAA concentration matches or more to EAA concentrations in fishmeal	Methionine, cystine may be limiting; not economical for large-scale use; crude fat and ash content is lower but can be overcome with supplementation
Canola meal	Not widely used in aquafeeds, similar to the protein content of SBM	The price similar to that of barley meal; low in available phosphorous
Canola protein concentrate	Protein content similar to high-quality fishmeal, widely tested as a protein source for salmonids and other carnivorous species of farmed fish, supports growth rates similar to those of fish fed fishmeal-based diets	Amino acid supplements needed to overcome limiting amino acid levels; feeding stimulants are needed to overcome reduced feed intake
Corn gluten meal	Crude protein content of 60–73%; corn gluten meal is currently widely used in aquafeeds for salmon and several marine species such as European seabass and gilthead seabream; highly digestible	Limited in commercial production; deficient in EAA lysine
Corn distillers dried grains with solubles (DDGS)	28–32% crude protein	High in fibre content
Cottonseed meal	10 and 30% of solvent extracted; 40% protein CSM can be used in aquaculture diets without growth depression	Presence of gossypol may have toxic effects

Peas/lupins	High protein apparent digestibility coefficient	Lysine and methionine are limited; high levels of carbohydrate (fish do not metabolize non–starch polysaccharides in lupins); presence of anti–nutrient quinolizidine alkaloids; lysine is limiting
Wheat	Low in protein (<11)	Wheat is primarily an energy source based on its high starch composition (typically >70%); lysine is limiting
Barley	Barley protein is well digested	Low crude protein content (9–15%); high in fibre; low in available phosphorous; lysine and arginine may be limiting; high in fibre

So if vegetable proteins are to be used more heavily in fish feed production, techniques and procedures aimed at reducing their anti-nutritional effects must be applied. Applying heat to the mixture is one approach, but that will only get you so far.

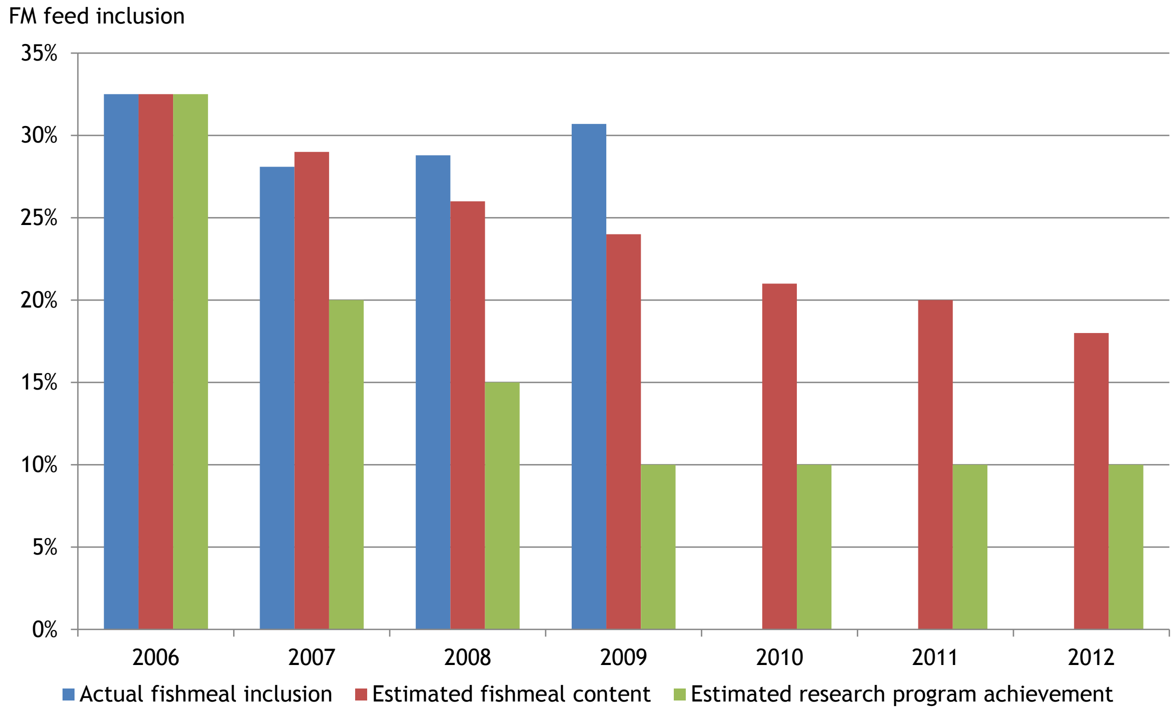
The French National Institute for Agriculture Research has initiated a research program called PEPPA (Perspectives of Plant Protein Use in Aquaculture) under the fifth framework of EU. The goal of this program is to reduce the dependency of fishmeal (and fish oil) in aquaculture production. Their targeted dependency ratio is presented in table 6.2. The project is still ongoing and they highlight that resolving the issue with anti-nutritional factors in plant proteins is a main goal. For salmon they project an inclusion rate of about 1/3 of today's rate, while for carp (which is heavily cultured in Asia) they estimate a diet without any use of fishmeal.

Table 6.2: PEPPA targeted fishmeal inclusion factors (Rana et al. 2009)

Species	Current inclusion (%)	Targeted inclusion (%)
Atlantic Salmon	35 – 47	12 -16
Rainbow trout	30 – 35	5
Sebream	40 – 45	15
Common Carp	20 - 25	0

The fish feed producer EWOS also has a corresponding research program for their salmon feed pellets, where they aim to replace costly fishmeal with plant materials. The blue bars represent EWOS' actual fishmeal inclusion rate in feed pellets reported in Cermaq's 2009 annual report (Cermaq 2010). The red bars show what they estimated in 2006 that the future inclusion level would be, the blue bars show actual inclusion level, while the green bars show what they projected that their research program would yield. The data shows that EWOS used slightly less fishmeal than estimated in 2007, but in 2008 and 2009 they used far more than estimated. This has happened despite an increasing fishmeal-soybean meal ratio over the period. So the fishmeal inclusion level has not progressed as they estimated in 2006. However, this is probably not enough evidence to conclude that the research has progressed slower than anticipated, as it might be a simple economic decision to deviate from the stipulated plan. EWOS' goal is set at 10 percent inclusion, which puts them slightly below PEPPA's target rate at 12 – 16 percent.

Figure 6.1: EWOS actual and targeted inclusion rates (Cermaq 2010 and EWOS 2009)



6.2 Plankton and algae

A research area that lately has received a lot of attention is the prospects of substituting fishmeal with microbial and plankton products. If this research is successful it will enable producers to skip a link in the energy chain: Pelagic fish that are ground to fishmeal have a high degree of fatty acid and proteins, but these valued substances are not produced by the fish itself. Rather, herbivorous consumers obtain it from consuming plankton, including copepods, euphausiids, krill and amphipods.

The Norwegian University of Science and Technology (NTNU) initiated in 2001 a research program called Calanus aimed at identifying opportunities for harvesting zoo plankton. The main objective of the program was to map the sustainable harvesting potential, develop efficient harvesting techniques and industrial processes, and evaluate the nutritional properties of raw materials with respect to fish feed. The research program is done at a basic level and not yet commercially viable. If successful however, the possibilities for the fish feed industry are remarkable as the ocean contains vast resources of herbivorous zooplankton. In the Norwegian Sea it is estimated to be 8 – 13 grams dry weight zooplankton per m^2 (Ellertsen et al. 1999 and Hassel 1999) and total production of the zooplankton Calanus is calculated at 21 million tons per year (Aksnes and Tande 1996 and Tande 1994). The Calanus biomass is of particular interest because it is highly similar to the natural diet of many feed fishes. However, developing catching methods for zooplankton is not straightforward. If the plankton is to be caught by a trawler, it will require nets with a mesh sizes at maximum 1 – 2 mm, which means high energy costs due to drag. In addition, a fine-meshed net like that has the capacity to take a bycatch consisting of virtually everything in its path.

Research on this area is still at an early stage, but if it should prove to be a commercially viable solution it will be a major catalyst for further aquaculture growth. According to the program's researchers, exploitation of zooplankton resources is probably the fastest and most sustainable way to enhance marine harvest of bio-resources for fish feed (FHF 2003).

6.3 Terrestrial insects and worms

Plankton and algae are not the only invertebrates that could be a viable protein source to replace fishmeal: Terrestrial insects and polychaete worms are also feasible sources. Examples of polychaetes are marine worms and earth worms. Earth worms contain on a dry basis 60-70 percent protein with high essential amino acid content, especially lysine and methionine. They also have 6-11 percent fat, 5-21 percent carbohydrate, 2-3 percent minerals and several vitamins. Among terrestrial insects, silkworm pupae, which contain a high content of free fatty acids, can be used.

The worms' nutrient content are thus to a large extent in line with the requirements to be a valid substitute for fishmeal. Therefore these worms are a potentially viable source of protein if they can be produced and processed economically. Researchers at the Institute of Aquaculture at the University of Stirling in Scotland investigated the nutritional value of dried earthworm meal (Eisenia foetida) included at low levels in rainbow trout diets as a replacement for herring meal (Stafford and Tacon 2008). Increasing levels of dried Eisenia meal from 5 – 30 percent were included in the diet and the response of fish fed these diets was compared to fish fed a control diet without earthworm meal inclusion. There was no evidence of any adverse effect on the growth performance or feed utilization efficiency of fish fed diets containing dried earthworm meal. Similar research with equivalent results, were performed by Bhilave and Nadaf at the Shivaji University, India (2010).

6.4 Animal by-products

Animal by-products already play an important role as an ingredient in aquaculture feed pellets. Table 6.3 shows their advantages/disadvantages as a substitute for fishmeal. Both poultry by-products and blood meal have to some degree proved to be partial substitutes for fishmeal (Kureshy et al. 2000). An example of this is Marine Harvest which used pellets including 12 percent poultry by-products and only 19 percent fishmeal at their Chilean salmon farms in 2008 (Marine Harvest 2010). In Europe however, there are regulations prohibiting the use of pig & poultry by-products in feed pellets, and Marine Harvest used in 2008 29 percent fishmeal in their European pellets. Even though there are probably other factors also influencing this difference in fishmeal usage, it is interesting to see how much lower the fishmeal inclusion rate in the Chilean operation is.

The most important by-product is however from aquaculture production itself. When fish is processed for human consumption, fins, guts, bones and heads are removed during processing. These parts are called trimmings and have a high protein content. The industry has therefore started to process trimmings into fishmeal, and it is estimated that approximately 25 percent of all fishmeal production now comes from trimmings (IFFO 2011). If aquaculture production increases as projected by Allen (2008) (cf. figure 1.3), then trimmings could become an even more important source of sustainable fishmeal supply. This is however contingent on future growth in the aquaculture production, and can thus not be the factor that fuels future aquaculture production. Better systems for collecting and processing trimmings could however stimulate increased fishmeal production without any reliance on aquaculture growth.

Table 6.3: Animal by-products as fishmeal substitutes (compiled by Rana et al. 2009)

Animal by-product substitute	Advantages	Disadvantages
Hydrolysed feather meal (HFM) (eithersteam or enzyme treated)	Proposed optimum replacement rates of fishmeal by enzyme treated HFM are; European seabass ≤5%, turbot ≤5%, gilthead seabream 5%, red tilapia <66%, rainbow trout <20%	Steam treated is less digestible compared with enzyme treated; deficient in lysine and methionine
Poultry by-product meal (PBM)	Typically contain 66% CP, 13% CF and 10-18% ash. Proposed optimum replacement rates of fishmeal by PBM are: European seabass 25%, turbot 10%, gilthead sea bream 25%, red tilapia 66%, rainbow trout 15%	Deficient in lysine, methionine and histidine
Blood meal	Rich in lysine	Deficient in methionine; highly sensitive to heat damage and drying conditions with profound effect on protein digestibility
Fish by-products from fish processing plants	Regarded as the best nutritional substitutes for fishmeal and fish oil due to their nutritional characteristics	Issues related to potential pathogens and contaminant harmful to both fish and consumers need to be addressed through proper treatment

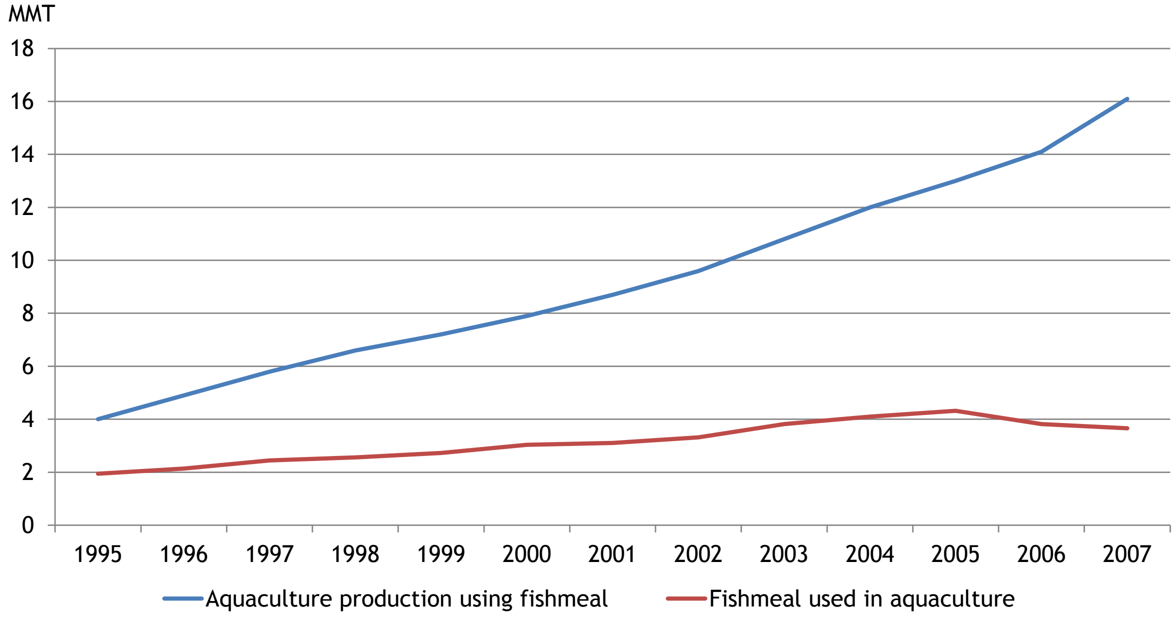
6.5 Discussion and research implications

The aim of this chapter was to provide an introductory overview to the main work being done on aquaculture feed compositions and illustrate that the industry are trying several approaches. In addition to the mentioned methods, there are also promising research being performed on gene modified soy beans (e.g. Monsanto), gene modifying carnivorous fish so it becomes more acceptable to vegetable proteins, development of new pharmaceutical nutrition supplements and enhancement of palatability of plant feedstuff. In addition, the Norwegian company Norferm is researching on a substance called Bioferm which is fish feed produced from natural gas, and they are experimenting with it in salmon diets.

So in the aquaculture feed industry there are both private and governmental research programs and new projects on the area are continuously initiated with large sums of money being devoted to the effort. Even though it is difficult to quantify how significant these programs will be, it is hard to argue that they will have a trivial effect on the future raw material balance for aquaculture feed production. The search for a sustainable raw material as an alternative to fishmeal is done on several levels, both with respect to initiatives and substances researched on. There are programs that already show commercial potential and other projects that are in its startup phase. As the world will demand more and more proteins to feed a growing population, it is likely that research efforts on aquaculture production will just intensify over time.

The programs have already come a long way and fishmeal inclusion rates at a commercial level now varies from 20 to 30 percent compared to 75 percent in the 1980's (EWOS 2009). This is furthermore illustrated when total aquaculture consumption of fishmeal with its compared to total aquaculture production level (see figure 6.2). The following graph shows that aquaculture production which uses fishmeal and/or fish oil in its production has increased from about 4 million tons in 1995 to over 16 million tons in 2007 – an increase of about 300 percent. Meanwhile, the total amount of fishmeal has only grown by 88 percent, from about 2 million tons in 1995 to 3.6 million tons in 2007. This shows that feed producers are managing the costly fishmeal resource more effectively than before.

Figure 6.2: Aquaculture production and consumption (Tacon 2008 and Kristofersson 2007)



7 Concluding comments

This paper explored if the limited availability of fishmeal could restrain the future growth of aquaculture production, i.e. examined the validity of the “fishmeal trap”.

By 2009 the number of people living in hunger was estimated to be nearly 1 050 million, an increase of 30 percent since 1995. Inadequate purchasing power in developing countries, nations living in protracting crisis and a strained food supply/demand balance are all contributing factors to the current food crisis. Increased aquaculture production could ease the situation due to favorable feed conversion ratios compared to terrestrial meat production. A large proportion of the cultivated fish is indigenously carnivorous and hence requires input of fishmeal in their feed diets. However, fishmeal exists at a limited yearly supply and production growth of carnivorous aquaculture species could therefore be hindered by the availability of fishmeal.

Chapter 2 showed that the yearly fishmeal production is about 5-6 million tons and that the South American fisheries are the most important contributors, providing about 40 percent of global fishmeal production. The El Niño phenomenon is considered to be the most significant volatility causing factor in yearly output and hence also providing volatility to the fishmeal price. The aquaculture sector has grown from being an insignificant consumer of fishmeal in the 1980’s to consume over half the world’s fishmeal supply in 2008. Along with the growth in aquaculture production the inclusion levels of fishmeal in fish feed diets has decreased, but the overall growth has still increased total fishmeal consumption by the aquaculture sector. China, which is the largest consumer of fishmeal, has now become the leading producer of soybean meal in order to meet the increasing domestic demand for proteins. It is expected that demand for soybean meal and other vegetable meals will increase in Asia going forward due to the high GDP and population growth.

In chapter 3 it was illustrated that if fishmeal and soybean meal markets could be proven to be integrated, then it could be argued that concerns regarding the fishmeal trap might be unjustified. A way to determine the degree of market integration is to utilize price data in cointegration analysis. Cointegration analysis was in chapter 5 applied to price series to determine whether fishmeal and soybean meal could be considered as substitutes, and if the aggregated substitution possibilities seemed to be diminishing as aquaculture production progressed.

When testing the whole dataset (year 1981 to 2010) I found proof for an equilibrium relationship between fishmeal and soybean meal markets. Fishmeal was in the long-run linked to soybean meal, meaning any deviations from the equilibrium would be corrected back. As expected, the same could not be established for the soybean meal price since the annual soybean meal production is 25 times the fishmeal production. The long-run equilibrium result is interesting as one might be led to believe that the rising fishmeal-soybean meal ratio during the period 1997 to 2010 would weaken any linkage established during the 1980's. But once the upward trend in the fishmeal price from 1997 – 2010 was accounted for, the fishmeal price could be proven to be influenced by the soybean meal price. The result shows that feed mill producers still view fishmeal and soybean meal as (imperfect) substitutes, even though the aquaculture sector has had a rapid growth the last years. The aggregated imperfection might however be growing over time (i.e. diminishing aggregated substitution possibilities between fishmeal and soybean meal) as aquaculture continues to play an increasingly important role in the fishmeal market. To shed more light on this the data was split into three time periods and tested for cointegration.

From 1981 to 1988 there was strong evidence of an equilibrium relationship between fishmeal and soybean meal prices. However, it was soybean meal that was linked in the long-run to fishmeal and not vice versa. Given the mentioned production quantity differences this might be a bit surprising. The findings are however in line with research done by Durand (1994) who examined a dataset ranging from 1977 to 1993. The result might indicate that the fishmeal market has a leading role relative to soybean meal, thus acting as a price leader. But considering the vast size of the soybean meal market compared to fishmeal, this is doubtful. Rather, a possible explanation could be that the frequent fluctuations in the fishmeal price causes uncertainty amongst market agents about future fishmeal prices, thus creating uncertainty about future meal substitute prices as well. This again could shift prices, giving the impression that fishmeal is acting as a price leader. Either way, the goal of this paper is not to dwell on this observation.

The next period examined ranged from 1989 to 1998, where aquaculture's global consumption share of fishmeal increased from 12 to 48 percent (cf. table 2.2). During this period it was not possible to establish any long-run equilibrium between fishmeal and soybean meal prices. This indicates that aquaculture producers value the non-protein characteristics of fishmeal more highly than terrestrial producers, and that the increased demand from aquaculture sector has caused the deterioration of the linkage between fishmeal and soybean meal. Furthermore, this result argues in favor of those concerned that the limited availability of fishmeal could restrain the future aquaculture growth. The cointegration result is in line with research done by Anderson and Kristofersson (2004) which examined price data from 1988 to 1996, but not in-line with Tveteraas' research (2000) on price series from 1986 to 1997. It might therefore not be clear whether fishmeal and soybean meal prices have been cointegrated during this period. However, given Anderson and Kristofersson's findings of structural breaks in 1995 and 1996 combined with my results that give no credit to a cointegration relationship during this period, I would argue that there has been a deterioration of the fishmeal-soybean meal relationship.

The third selected period was 1999 to 2010 which is characterized by increasing fishmeal prices and a continuing high fishmeal demand from the aquaculture sector. However, when the upward trend in the fishmeal price was accounted for there was some evidence of a cointegration relation between fishmeal and soybean meal. This means that even though aquaculture producers view fishmeal as a superior product compared to soybean meal, they still consider their relative prices before determining the feed composition. Kristofersson (2007b) argues that there is a "breakdown of long run close price relationship between fishmeal and oil soy substitutes, indicating falling substitutability". My results does state this to some degree, but I would not go as far as saying that there has been a complete breakdown in the long-run relationship as the two products still are regarded as substitutes. However, it is clear that the long-run relationship is weakening and thus strengthening the validity of the fishmeal trap.

In chapter 6 an introduction to some of the main research efforts on fish feed diets were given. Several projects aimed at reducing the inclusion level of fishmeal have been ongoing for some time now and many of them show promising preliminary results. The programs are not concentrated around one approach, but research is performed on several frontiers. The European research program PEPPA has targeted inclusion rates 65 to 100 percent less than today's rates for various carnivorous species, and if successful it will have a significant impact on aquaculture production possibilities. Scientists at the Norwegian University of Science and Technology (NTNU) claim that exploitation of zooplankton could be the fastest and most sustainable way to enhance marine harvest of bio-resources for fish feed. Other promising approaches are feed production from earth worms and increasing the use of animal by-products. Considering the number of research programs and money being devoted to find alternatives for fishmeal, it is likely that fishmeal inclusion rates in fish feed diets could be substantially reduced in the future. This argues against the validity of the fishmeal trap.

So the statistical analysis and the qualitative discussion of research efforts might be somewhat contradictory when it comes to exploring the validity of the fishmeal-trap. It is likely that there will be a downward trend in the fishmeal inclusion level over time, but as aquaculture production grows at a rapid rate (cf. figure 1.3) the demand for fishmeal is not expected to decrease. The statistical analysis points out that soybean meal is not a perfect substitute for fishmeal, and this implies that it will continue to be a strained fishmeal supply/demand balance in the short term. Long-term it does however seem that research initiatives will come up with solutions that enables production with minimal inclusions of fishmeal, thus allowing increased aquaculture production of carnivorous fish. However, if commercially viable solutions from research programs are delayed, then aquaculture production of carnivorous fish could be restrained for some time.

One way to increase aquaculture production irrespective of research progress could be to cultivate more non-carnivorous fish species. Carnivorous fish production in 2007 made up about 31 percent of total aquaculture production and the remaining 69 percent was non-carnivorous fish (cf. figure 1.3 and 6.2), where carp and molluscs (e.g. squid) are the most important non-carnivorous species. Aquaculture production could therefore be increased by focusing the growth on non-carnivorous species. However, market forces and governmental policies in many countries favor rapid expansion of carnivorous species such as salmon and shrimp (Naylor et al. 2000).

All in all, is there any validity to the fishmeal trap? In the short-run I would argue that there is, as the statistical analysis shows that the fishmeal and soybean meal markets are becoming increasingly disconnected. In the long-run however, research initiatives are likely to provide substances which are near complete substitutes to fishmeal. Also, increased cultivation of non-carnivorous species and reduction of the fishmeal used in their diets could stimulate further growth. I would therefore say that there is little validity to the fishmeal trap in the long-term, and I find it probable that the aquaculture sector will continue to adapt to technological development and play a more important role in feeding the world's population in the future.

8 The data series

fm(t) = International market price for fishmeal (monthly average), 64/65%, any origin, wholesale, CIF Hamburg, Jan 1981- April 2009,, in US$/tonne

sm(t) = International market prices for soybean meal (monthly averages), 44%, any origin, CIF Rotterdam/Hamburg, Jan 1981-April 2009, in US$/tonne

1981 – 2008: Globefish (Commodity update, 2009)

2009 – 2010: International Monetary Fund (IMF, 2011)

Year	Month	fm(t)	sm(t)	Year	Month	fm(t)	sm(t)
1981	1	541	287	1996	1	649	275
1981	2	518	270	1996	2	641	264
1981	3	507	265	1996	3	616	260
1981	4	501	273	1996	4	583	273
1981	5	504	267	1996	5	564	276
1981	6	485	248	1996	6	563	269
1981	7	470	247	1996	7	547	271
1981	8	439	243	1996	8	539	278
1981	9	434	235	1996	9	566	292
1981	10	405	231	1996	10	581	274
1981	11	407	230	1996	11	600	285
1981	12	399	236	1996	12	583	279
1982	1	390	242	1997	1	576	283
1982	2	369	235	1997	2	558	298
1982	3	357	226	1997	3	554	325
1982	4	357	230	1997	4	545	304
1982	5	362	234	1997	5	548	308
1982	6	348	222	1997	6	558	284
1982	7	335	212	1997	7	581	261
1982	8	320	203	1997	8	621	276
1982	9	319	195	1997	9	637	301
1982	10	326	192	1997	10	658	267
1982	11	353	213	1997	11	716	294
1982	12	399	217	1997	12	721	276
1983	1	439	216	1998	1	703	249
1983	2	423	211	1998	2	699	230
1983	3	403	211	1998	3	682	212
1983	4	440	219	1998	4	684	188
1983	5	437	217	1998	5	685	187
1983	6	430	210	1998	6	675	182

1983	7	433	226	1998	7	660	176
1983	8	452	279	1998	8	670	168
1983	9	503	277	1998	9	681	167
1983	10	510	267	1998	10	662	166
1983	11	479	265	1998	11	601	174
1983	12	482	256	1998	12	541	174
1984	1	480	237	1999	1	500	163
1984	2	466	221	1999	2	454	153
1984	3	428	229	1999	3	406	161
1984	4	402	220	1999	4	348	166
1984	5	382	219	1999	5	337	151
1984	6	372	202	1999	6	345	150
1984	7	341	186	1999	7	355	160
1984	8	333	180	1999	8	371	164
1984	9	318	168	1999	9	382	179
1984	10	319	170	1999	10	399	184
1984	11	323	169	1999	11	401	178
1984	12	314	165	1999	12	412	175
1985	1	307	166	2000	1	416	185
1985	2	292	151	2000	2	407	194
1985	3	280	154	2000	3	392	199
1985	4	271	151	2000	4	385	198
1985	5	276	144	2000	5	385	204
1985	6	256	141	2000	6	420	196
1985	7	254	144	2000	7	423	183
1985	8	259	150	2000	8	417	186
1985	9	265	160	2000	9	419	207
1985	10	287	170	2000	10	414	204
1985	11	308	177	2000	11	413	210
1985	12	306	178	2000	12	463	230
1986	1	292	186	2001	1	480	218
1986	2	292	185	2001	2	470	200
1986	3	321	194	2001	3	443	195
1986	4	333	187	2001	4	436	189
1986	5	317	184	2001	5	369	182
1986	6	317	180	2001	6	413	202
1986	7	319	184	2001	7	461	205
1986	8	326	187	2001	8	515	202
1986	9	339	189	2001	9	507	203
1986	10	353	187	2001	10	509	197
1986	11	328	185	2001	11	543	195
1986	12	310	183	2001	12	573	180
1987	1	317	182	2002	1	585	182
1987	2	322	183	2002	2	590	181
1987	3	332	175	2002	3	593	179
1987	4	341	185	2002	4	609	179

1987	5	362	201	2002	5	625	188
1987	6	395	235	2002	6	631	190
1987	7	403	204	2002	7	619	200
1987	8	413	194	2002	8	617	196
1987	9	400	207	2002	9	615	206
1987	10	406	214	2002	10	606	198
1987	11	430	235	2002	11	593	199
1987	12	474	241	2002	12	585	193
1988	1	473	239	2003	1	607	197
1988	2	473	233	2003	2	590	204
1988	3	487	247	2003	3	577	198
1988	4	520	258	2003	4	577	204
1988	5	541	255	2003	5	599	212
1988	6	606	317	2003	6	630	211
1988	7	610	293	2003	7	617	203
1988	8	577	280	2003	8	597	209
1988	9	582	297	2003	9	608	223
1988	10	571	290	2003	10	624	265
1988	11	543	286	2003	11	648	284
1988	12	534	287	2003	12	656	277
1989	1	481	288	2004	1	682	293
1989	2	464	270	2004	2	685	292
1989	3	437	277	2004	3	665	321
1989	4	400	264	2004	4	645	313
1989	5	413	264	2004	5	643	299
1989	6	371	254	2004	6	645	254
1989	7	380	255	2004	7	638	227
1989	8	360	225	2004	8	626	217
1989	9	360	216	2004	9	625	214
1989	10	393	222	2004	10	629	210
1989	11	418	227	2004	11	643	210
1989	12	438	229	2004	12	654	213
1990	1	430	223	2005	1	628	222
1990	2	426	216	2005	2	641	235
1990	3	385	211	2005	3	653	250
1990	4	381	217	2005	4	655	245
1990	5	374	215	2005	5	663	235
1990	6	354	206	2005	6	672	238
1990	7	383	208	2005	7	694	247
1990	8	405	206	2005	8	715	235
1990	9	417	212	2005	9	727	225
1990	10	435	227	2005	10	793	217
1990	11	477	207	2005	11	841	215
1990	12	485	213	2005	12	851	228
1991	1	480	208	2006	1	883	219
1991	2	485	211	2006	2	875	218

1991	3	455	202	2006	3	885	218
1991	4	459	204	2006	4	900	218
1991	5	467	217	2006	5	1075	220
1991	6	482	211	2006	6	1340	209
1991	7	471	197	2006	7	1379	207
1991	8	444	197	2006	8	1358	216
1991	9	478	218	2006	9	1267	222
1991	10	498	215	2006	10	1229	230
1991	11	508	211	2006	11	1247	246
1991	12	500	210	2006	12	1256	245
1992	1	500	221	2007	1	1234	257
1992	2	494	216	2007	2	1252	272
1992	3	488	213	2007	3	1268	278
1992	4	489	210	2007	4	1289	263
1992	5	495	212	2007	5	1264	268
1992	6	497	218	2007	6	1224	279
1992	7	485	220	2007	7	1202	294
1992	8	493	224	2007	8	1087	310
1992	9	481	229	2007	9	1058	336
1992	10	469	216	2007	10	1072	411
1992	11	455	208	2007	11	1069	414
1992	12	438	222	2007	12	1088	443
1993	1	418	224	2008	1	1103	454
1993	2	391	216	2008	2	1114	469
1993	3	377	208	2008	3	1161	489
1993	4	361	209	2008	4	1168	541
1993	5	347	207	2008	5	1211	509
1993	6	348	209	2008	6	1201	520
1993	7	356	239	2008	7	1232	515
1993	8	358	237	2008	8	1188	458
1993	9	353	228	2008	9	1173	411
1993	10	339	219	2008	10	1051	358
1993	11	360	226	2008	11	995	347
1993	12	367	225	2008	12	984	329
1994	1	366	225	2009	1	1009	378
1994	2	364	220	2009	2	997	385
1994	3	352	221	2009	3	1030	374
1994	4	351	219	2009	4	1038	380
1994	5	360	210	2009	5	1103	408
1994	6	365	214	2009	6	1149	442
1994	7	376	209	2009	7	1208	386
1994	8	379	208	2009	8	1272	397
1994	9	392	206	2009	9	1348	342
1994	10	398	196	2009	10	1427	329
1994	11	394	187	2009	11	1526	338
1994	12	418	187	2009	12	1651	346

1995	1	435	191	2010	1	1681	326
1995	2	437	195	2010	2	1627	304
1995	3	447	206	2010	3	1672	293
1995	4	447	203	2010	4	1874	308
1995	5	435	188	2010	5	1821	306
1995	6	467	180	2010	6	1747	314
1995	7	502	193	2010	7	1715	335
1995	8	493	198	2010	8	1629	339
1995	9	505	219	2010	9	1645	334
1995	10	522	228	2010	10	1710	354
1995	11	618	237	2010	11	1609	376
1995	12	647	264	2010	12	1520	388

9 Appendix

Figure A.1: Global fisheries production: capture fisheries and aquaculture 1984 – 2004 (FAO, 2005)

Figure 4.1. Global fisheries production: capture fisheries and aquaculture 1984-2004.

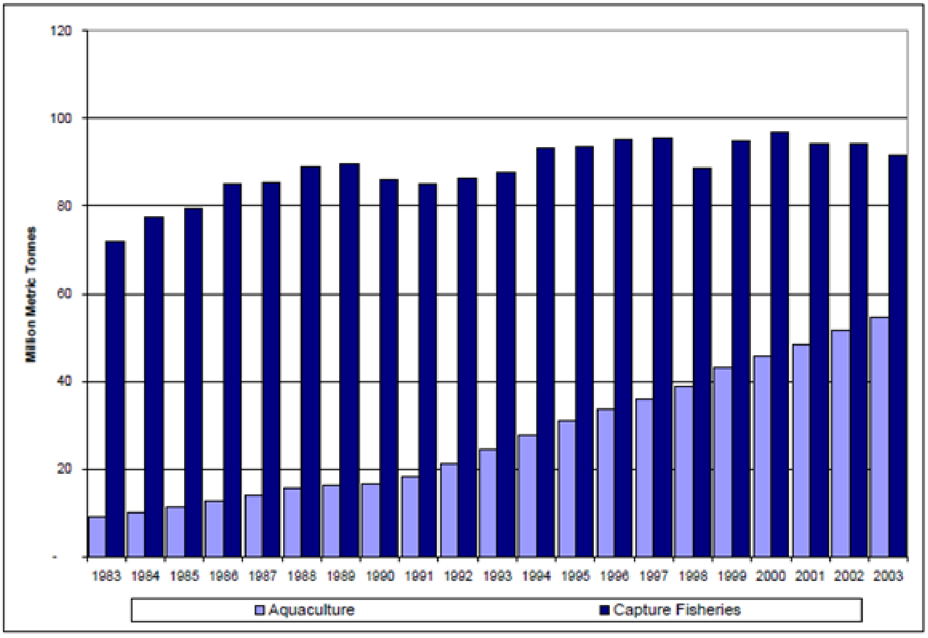


Figure A.2: Commodity prices (Bloomberg)

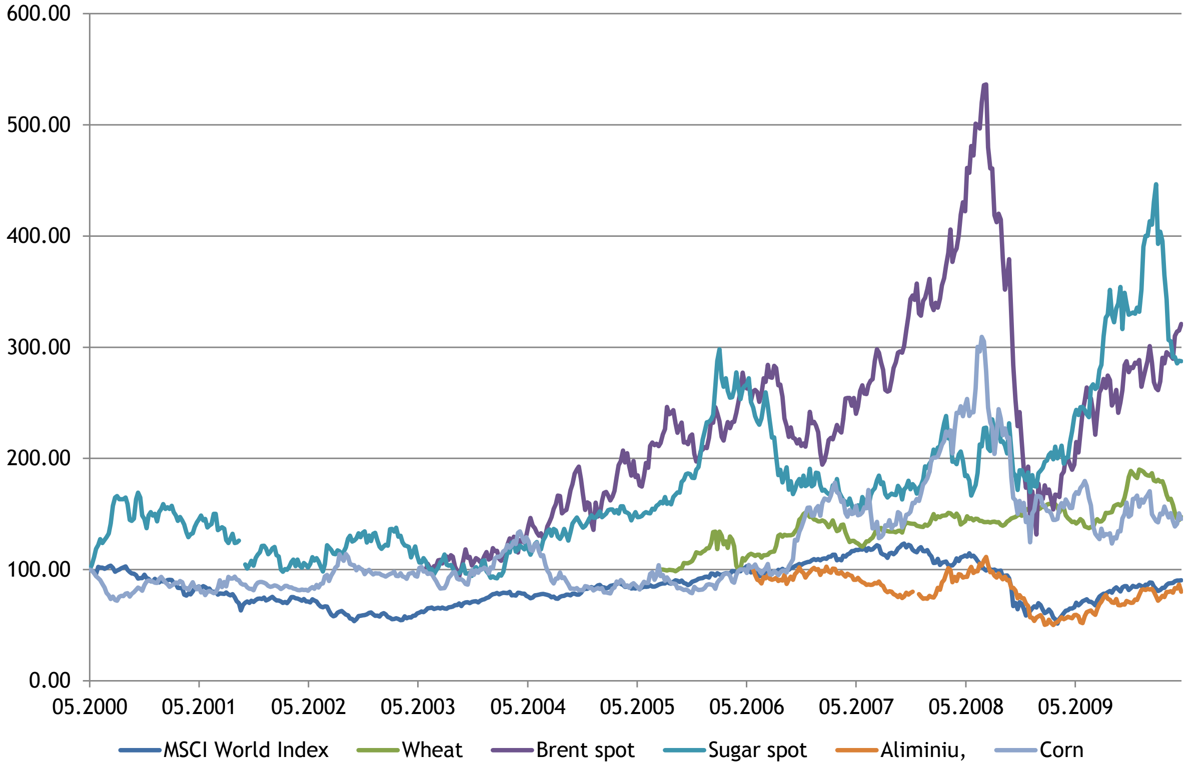


Table A.1: Long-run relationship estimation 1981 - 2010

```
      Source |       SS       df       MS              Number of obs =     360
-------------+------------------------------           F(  2,   357) =  700.68
       Model |  31935919.6     2  15967959.8           Prob > F      =  0.0000
    Residual |  8135757.06   357  22789.2354           R-squared     =  0.7970
-------------+------------------------------           Adj R-squared =  0.7958
       Total |  40071676.7   359  111620.269           Root MSE      =  150.96

------------------------------------------------------------------------------
         fmt |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         smt |   1.187336   .1458356     8.14   0.000     .9005313    1.474141
          dt |   4.560522   .1822656    25.02   0.000     4.202073    4.918971
       _cons |   145.3496   32.23315     4.51   0.000     81.95892    208.7403
```

Table A.2: Testing for cointegration 1981 - 2010

```
Augmented Dickey-Fuller test for unit root         Number of obs   =       353

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -5.130            -2.580            -1.950            -1.620

------------------------------------------------------------------------------
        D.u1 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          u1 |
         L1. |  -.0686221   .0133769    -5.13   0.000    -.0949325   -.0423118
         LD. |   .4152626    .051866     8.01   0.000     .3132503    .5172749
        L2D. |   .0113188   .0576562     0.20   0.844    -.1020819    .1247195
        L3D. |   .0277819   .0579746     0.48   0.632    -.0862451    .1418089
        L4D. |     .08787   .0578704     1.52   0.130    -.0259522    .2016921
        L5D. |   .0750949   .0587576     1.28   0.202    -.0404722     .190662
        L6D. |   .1380776   .0561909     2.46   0.014     .0275589    .2485963
------------------------------------------------------------------------------
```

Table A.3: AIC and SBC for fishmeal and soybean meal

delta_fmt

```
   Selection-order criteria
   Sample:  7 - 360                                  Number of obs      =       354
  +---------------------------------------------------------------------------+
  |lag |    LL      LR      df    p      FPE       AIC      HQIC      SBIC    |
  |----+----------------------------------------------------------------------|
  |  0 | -1761.01                      1232.74   9.95487   9.95922    9.9658  |
  |  1 | -1724.41    73.2     1  0.000  1008.14   9.75374   9.76244    9.7756* |
  |  2 |  -1722.4  4.0274*    1  0.045  1002.38*  9.74801*  9.76106*   9.7808  |
  |  3 | -1721.72  1.3525     1  0.245  1004.22   9.74984   9.76724   9.79356  |
  |  4 | -1721.47   .5047     1  0.477  1008.47   9.75407   9.77581   9.80872  |
  |  5 | -1720.63  1.6749     1  0.196   1009.4   9.75498   9.78108   9.82057  |
  +---------------------------------------------------------------------------+
```

delta_smt

```
   Selection-order criteria
   Sample:  7 - 360                                  Number of obs      =       354
  +---------------------------------------------------------------------------+
  |lag |    LL      LR      df    p      FPE       AIC      HQIC      SBIC    |
  |----+----------------------------------------------------------------------|
  |  0 | -1463.51                      229.572   8.27409   8.27844   8.28502  |
  |  1 | -1459.05  8.9225*    1  0.003  225.126   8.25454   8.26324*   8.2764* |
  |  2 | -1457.96   2.178     1  0.140  225.013*  8.25404*  8.26708   8.28683  |
  |  3 | -1457.66  .59971     1  0.439  225.905   8.25799   8.27539   8.30171  |
  |  4 | -1457.63  .07105     1  0.790   227.14   8.26344   8.28518   8.31809  |
  |  5 | -1456.78  1.6881     1  0.194   227.34   8.26432   8.29041    8.3299  |
  +---------------------------------------------------------------------------+
```

Table A.4: Vector Error-Correction Model 1981 - 2010

```
Vector autoregression

Sample:  3 - 360                                   No. of obs      =       358
Log likelihood =  -3203.91                         AIC             =  17.94363
FPE            =  212751.8                         HQIC            =  17.97812
Det(Sigma_ml)  =  203452.3                         SBIC            =  18.03035

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
delta_fmt             4     31.1016   0.2122   96.44805   0.0000
delta_smt             4     14.9127   0.0318   11.76475   0.0082
----------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
delta_fmt    |
   delta_fmt |
         L1. |   .4547524   .0481947     9.44   0.000     .3602925    .5492122
             |
   delta_smt |
         L1. |  -.0025155   .1097308    -0.02   0.982    -.2175839    .2125529
             |
      lag_u1 |   -.036998   .0109513    -3.38   0.001    -.0584622   -.0155338
       _cons |   1.421926   1.640807     0.87   0.386    -1.793997    4.637849
-------------+----------------------------------------------------------------
delta_smt    |
   delta_fmt |
         L1. |  -.0280485   .0231086    -1.21   0.225    -.0733406    .0172435
             |
   delta_smt |
         L1. |   .1703174   .0526143     3.24   0.001     .0671953    .2734394
             |
      lag_u1 |   .0060197    .005251     1.15   0.252     -.004272    .0163115
       _cons |   .3743511   .7867424     0.48   0.634    -1.167636    1.916338
------------------------------------------------------------------------------
```

```
 Lagrange-multiplier test
+--------------------------------------+
| lag |      chi2    df   Prob > chi2 |
|-----+--------------------------------|
|   1 |    7.4496     4     0.11395   |
|   2 |    8.6151     4     0.07147   |
+--------------------------------------+
 H0: no autocorrelation at lag order
```

Table A.5: VECM for year 1981 – 1988

```
. var delta_fmt delta_smt in 1/96, lags(1/1) exog(lag_u2)

Vector autoregression

Sample:  3 - 96                                  No. of obs      =        94
Log likelihood = -748.6542                       AIC             =  16.09902
FPE            =  33636.71                       HQIC            =  16.18645
Det(Sigma_ml)  =  28369.15                       SBIC            =  16.31548

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
delta_fmt             4     17.1958   0.2632   33.57183   0.0000
delta_smt             4     12.8252   0.0793   8.09099    0.0442
----------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
delta_fmt    |
   delta_fmt |
         L1. |   .2304127   .1064023     2.17   0.030      .021868    .4389574
             |
   delta_smt |
         L1. |   .5125762   .1661066     3.09   0.002     .1870131    .8381392
             |
      lag_u2 |  -.0229841   .0603486    -0.38   0.703    -.1412652    .0952969
       _cons |   .1733896   1.735479     0.10   0.920    -3.228086    3.574865
-------------+----------------------------------------------------------------
delta_smt    |
   delta_fmt |
         L1. |   -.044075   .0793583    -0.56   0.579    -.1996144    .1114644
             |
   delta_smt |
         L1. |   .1567771   .1238877     1.27   0.206    -.0860383    .3995926
             |
      lag_u2 |   .1267719   .0450099     2.82   0.005     .0385541    .2149898
       _cons |   .1689712   1.294376     0.13   0.896    -2.367959    2.705902
```

Table A.6: VECM for year 1999 - 2010

```
Vector autoregression

Sample:  217 - 360                                  No. of obs      =       144
Log likelihood = -1360.981                          AIC             =  19.01363
FPE            =  620265.6                          HQIC            =  19.08067
Det(Sigma_ml)  =  555022.2                          SBIC            =  19.17862

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
delta_fmt            4     43.3149   0.2215   40.97014   0.0000
delta_smt            4     17.7944   0.0784   12.25411   0.0066
----------------------------------------------------------------

------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
delta_fmt    |
   delta_fmt |
         L1. |   .4609414   .0747791     6.16   0.000      .314377    .6075057
             |
   delta_smt |
         L1. |  -.0298156   .1951698    -0.15   0.879    -.4123413    .3527101
             |
      lag_u4 |  -.0485592   .0192814    -2.52   0.012    -.0863501   -.0107683
       _cons |   1.801232   3.689874     0.49   0.625    -5.430788    9.033252
-------------+----------------------------------------------------------------
delta_smt    |
   delta_fmt |
         L1. |  -.0417612   .0307203    -1.36   0.174    -.1019719    .0184496
             |
   delta_smt |
         L1. |   .2548742   .0801786     3.18   0.001      .097727    .4120213
             |
      lag_u4 |   .0080625   .0079211     1.02   0.309    -.0074625    .0235876
       _cons |   1.721864   1.515854     1.14   0.256    -1.249155    4.692883
------------------------------------------------------------------------------
```

Table A.7: Long-run relationship estimation 1999 - 2005

```
      Source |       SS       df       MS              Number of obs =      84
-------------+------------------------------           F(  2,    81) =  244.53
       Model |  1066514.01     2  533257.003           Prob > F      =  0.0000
    Residual |  176636.804    81  2180.70129           R-squared     =  0.8579
-------------+------------------------------           Adj R-squared =  0.8544
       Total |  1243150.81    83  14977.7206           Root MSE      =  46.698

------------------------------------------------------------------------------
         fmt |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         smt |  -.1704467   .1968327    -0.87   0.389    -.5620821    .2211887
         t99 |   4.812606   .2868081    16.78   0.000     4.241948    5.383264
       _cons |   382.2574   34.46999    11.09   0.000     313.6729    450.8418
------------------------------------------------------------------------------
```

Table A.8: Cointegration test of the long-run relationship 1999 - 2005

```
Augmented Dickey-Fuller test for unit root         Number of obs   =        82

                               ────────── Interpolated Dickey-Fuller ─────────
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
──────────────────────────────────────────────────────────────────────────────
 Z(t)             -3.624            -2.607            -1.950            -1.610

──────────────────────────────────────────────────────────────────────────────
       D.u10 │      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
─────────────┼────────────────────────────────────────────────────────────────
         u10 │
         L1. │   -.194113   .0535691    -3.62   0.001    -.3007826   -.0874434
         LD. │   .4429299   .1022985     4.33   0.000     .2392276    .6466321
        L2D. │   .0100934   .1130037     0.09   0.929    -.2149257    .2351125
        L3D. │   -.066599   .1139859    -0.58   0.561    -.2935739    .1603759
        L4D. │   .2017106   .1011567     1.99   0.050      .000282    .4031393
──────────────────────────────────────────────────────────────────────────────
```

Table A.9: Error-Correction model 1999 - 2005

```
Vector autoregression

Sample:  219 - 300                                 No. of obs      =        82
Log likelihood =  -671.428                         AIC             =  16.57141
FPE            =   53950.1                         HQIC            =  16.66568
Det(Sigma_ml)  =  44379.72                         SBIC            =  16.80622

Equation           Parms      RMSE     R-sq      chi2     P>chi2
────────────────────────────────────────────────────────────────
delta_fmt            4     19.2282   0.2805   31.96718   0.0000
delta_smt            4      11.611   0.1081   9.940875   0.0191
────────────────────────────────────────────────────────────────

──────────────────────────────────────────────────────────────────────────────
             │      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
─────────────┼────────────────────────────────────────────────────────────────
delta_fmt    │
   delta_fmt │
         L1. │   .4490063   .0935432     4.80   0.000      .265665    .6323477
             │
   delta_smt │
         L1. │   .1404741    .174233     0.81   0.420    -.2010163    .4819645
             │
     lag_u10 │  -.1816171   .0502715    -3.61   0.000    -.2801475   -.0830867
       _cons │   2.344622    2.11863     1.11   0.268    -1.807817    6.497061
─────────────┼────────────────────────────────────────────────────────────────
delta_smt    │
   delta_fmt │
         L1. │  -.0541398   .0564863    -0.96   0.338    -.1648509    .0565714
             │
   delta_smt │
         L1. │   .3248891    .105211     3.09   0.002     .1186792     .531099
             │
     lag_u10 │   -.002746   .0303566    -0.09   0.928    -.0622439    .0567518
       _cons │   .9255761    1.27934     0.72   0.469    -1.581885    3.433037
──────────────────────────────────────────────────────────────────────────────
```

```
   Lagrange-multiplier test
  ┌──────────────────────────────────────┐
  │ lag  │      chi2    df   Prob > chi2 │
  │──────┼───────────────────────────────│
  │   1  │    3.9621     4     0.41116   │
  │   2  │    7.2398     4     0.12375   │
  └──────────────────────────────────────┘
   H0: no autocorrelation at lag order
```

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