Investigating Short- and Long-Run Linkages between Crude Oil and European Animal Feed Prices

Stefan van Merrienboer

Wageningen, May 2014

Investigating Short- and Long-Run Linkages between Crude Oil and European Animal Feed Prices

MSc Thesis

Author:	S.F.A. (Stefan) van Merrienboer BSc
Registration number:	880510559110
Supervisor:	Dr. Ir. W.E. Kuiper
Examiner:	Prof. Dr. Ir. A.G.J.M. Oude Lansink
Chair group:	Business Economics
Course code:	BEC-80433
University:	Wageningen University and Research centre
Period:	Summer 2013 – Spring 2014

Acknowledgements

With finishing my MSc thesis on the topic of price and price volatility linkages between crude oil and European animal feed markets, my study Management, Economics and Consumer studies at Wageningen University comes to an end. Before I can close this chapter, I would like to thank the following people.

Dr. Ir. Erno Kuiper, my supervisor for this project. Thank you very much for all your help and our regular discussions on VAR, ARCH, cointegration, Eviews and other topics we could find. Without your help I would not have finished this project. My girlfriend, Christine for her understanding and love during the period I was writing this thesis. My parents, Robert en Marjo for their support and offering me the opportunity to pursue my studies, although it took a couple of years longer than originally expected. Finally I would like to thank all my friends, who made my time in Wageningen, Germany and Washington, DC, such a great experience!

Summary

The last decade was marked by high and volatile prices for a broad range of agricultural commodities. This change in commodity price behaviour occurred after several decades of decreasing prices. Impacting not only the world's poor, causing 'food riots' in several African countries, but also affecting industrialised nations by introducing new uncertainties in the global economy. Focusing on the European agricultural sector, one of the sectors mostly affected by uncertain commodity prices is the livestock sector. Up to 90% of its main inputs are derived from agricultural commodities (e.g. wheat, barley, rye, soy) and the sector is faced with inelastic demand and supply functions making it extra vulnerable for changes in commodity price behaviour. A potential culprit through which this change in price behaviour is introduced is the link between crude oil markets and European animal feed markets.

Therefore, this thesis sets out to investigate the price relationship between crude oil markets and the European animal feed market for the period between January 1991 and December 2013, using literature study and empirical modelling. The aim of the literature study is to describe a relevant theoretical framework, linking crude oil markets and European animal feed markets. The empirical models designed try to analyse short- and long-term price relationships. In order to investigate the long-term dynamics the Two-Step Engle-Granger and Johansen cointegration tests were employed. Short-term price and price volatility behaviour was investigated using an approach testing for Granger causality. All models were estimated using EViews, a statistical software package geared to analyse time series econometrics. The data used for this thesis is monthly price data on Brent- and WTI crude oil, whilst the market for European animal feed is depicted by the monthly prices for selected animal feed commodities; oats, wheat, maize, barley, rye and soy meal.

The results show that there is no long-term price relationship between crude oil markets and European animal feed markets. Both the Two-step Engle-Granger as well as the Johansen cointegration tests reject the null hypothesis of cointegration for all bi-variate cases. Results for short-term price dynamics between crude oil and European animal feed prices yield a different outcome. Namely that the prices of maize and soy meal do Granger cause the prices of crude oil for the period January 1991 to December 2013. Similar results were obtained for the sub period January 2002 to December 2013, with the exception that during this period the prices of crude oil Granger cause the price of oats. Focusing on potential volatility transmission, using the Granger causality test, only rye Granger causes crude oil for the whole sample. This result is maintained in the second sub period in which rye is joined by maize.

Overall, the results show a change in price regime, changing from a regime in which crude oil and European animal markets are not interlinked, since no cointegration nor Granger causality is found for the first sub period January 1991 to December 2001, to a regime in which both markets are interlinked for some products, found in the second sub period running from December 2002 to January 2013.

The results support several studies, which also find more interlinked commodity markets in the last decade.

Table of Contents

1 Introduction 6
1.1 Background 6
1.2 Problem statement 8
1.3 Objective and research questions 8
1.4 Outline of report 8
2 Market structure 9
2.1 Common attributes of market structure 9
2.2 The world crude oil market 9
2.3 European animal feed market 10
2.4 Market linkages 12
2.4.1 Direct oil/feed links 12
2.4.2 Common oil/feed links 13
3 Data 15
4 Methodology 21
4.1 Unit root 21
4.1.1 Augmented Dickey-Fuller test 21
4.2 Cointegration 22
4.2.1 Two-step Engle-Granger cointegration test 22
4.2.2 Johansen cointegration test 22
4.3 Granger causality 23
4.3.1 Granger causality testing 23
5 Results 25
5.1 Unit root 25
5.2 Cointegration 27
5.2.1 Two-step Engle-Granger cointegration test 27
5.2.2 Johansen cointegration tests 29
5.3 Granger causality 32
5.3.1 Granger causality in levels 32
5.3.2 Granger causality in price volatility 35
6 Discussion 38
6.1 Data 38
6.2 Methodology 38
6.3 Results 39

7 Conclusion and Future Research 40
References 41

List of Figures

Figure 1 Monthly FAO food price index January 2000 to June 2013 (2002-2004 = 100). Source: (FAO 2013). 6
Figure 2 Animal feed sourcing EU-27 in 2012. Source: (FEFAC 2013). 7
Figure 3 Value of purchased compound feed in total animal output value in 2011. Source: (FEFAC 2012) 11
Figure 4 Feed material consumption by the compound feed industry in 2012, EU-27. Source: (FEFAC 2012). 11
Figure 5 Nominal monthly crude oil prices for 1991 to 2013 in €/barrel. Source: (EIA; World Bank).....16
Figure 6 Nominal monthly prices for selected animal feed commodities for 1991 to 2013 in €/metric tonne. Source: (EC; World Bank). 17
Figure 7 Monthly price volatility crude oil prices for 1991 to 2013. Source: Author's own work based on (EIA; World Bank). 19
Figure 8 Monthly price volatility selected animal feed commodities for 1991 to 2013. Source: Author's own work based on (EC; World Bank 2014). 19
Figure 9 Residuals crude oil and feed wheat. 28
Figure 10 Residuals crude oil and feed barley. 28
Figure 11 Residuals crude oil and feed maize. 28

List of Tables

Table 1 Price series data description. 15
Table 2 Correlation matrix of all commodities, period 1991-2013. 17
Table 3 Descriptive statistics of all employed price series, 1991 to 2013. 18
Table 4 Coefficients of variation all employed price series in multiple periods. 20
Table 5 ADF results for all price series. 26
Table 6 Results two-step Engle-Granger cointegration test. 27
Table 7 Results Johansen cointegration tests 1991-2013. 30
Table 8 Results Johansen cointegration tests 1991-2001 and 2002-2013. 31
Table 9 Results Granger causality tests in levels, 1991-2013. 32
Table 10 Results Granger causality tests in levels, 1991-2001. 33
Table 11 Results Granger causality tests in levels, 2002-2013. 34
Table 12 Results Granger causality tests in price volatilities, 1991-2013. 35
Table 13 Results Granger causality tests in price volatilities, 1991-2001. 36
Table 14 Results Granger causality tests in price volatilities, 2002-2013. 37

1 Introduction

The first chapter of this thesis aims at introducing the background of the chosen subject in Section 1.1. Section 1.2 postulates the problem statement. In Section 1.3 the general and specific research objectives are formulated that will be addressed in this study. Finally, Section 1.4 gives an overview of the further outline of this report.

1.1 Background

The last decade was marked by high and extremely volatile prices for a wide range of commodities. This change in commodity price behaviour occurred after several decades of low and stable prices. In particular, the prices for food commodities showed extraordinary behaviour, with food commodity prices starting to increase in 2002 and more than doubled between 2005 and 2008. This led to the initial 'price spike' in 2008 and subsequent global food crisis of 2007-2008, causing 'food riots' in several African countries and pushing millions of already poverty-stricken people further into destitution (Berazneva and Lee 2013). On the contrary, initiated by the global financial crisis, prices for food commodities started to decrease in a similar dramatic fashion, reaching pre-crisis levels at the beginning of 2009. After this initial boom and bust cycle, food commodity prices exhibited another rally, peaking in February 2011 at a level higher than during the food crisis of 2007-2008, staying above long-term trends ever since. Figure 1 shows the monthly FAO food price index over the period January 2000 till June 2013.

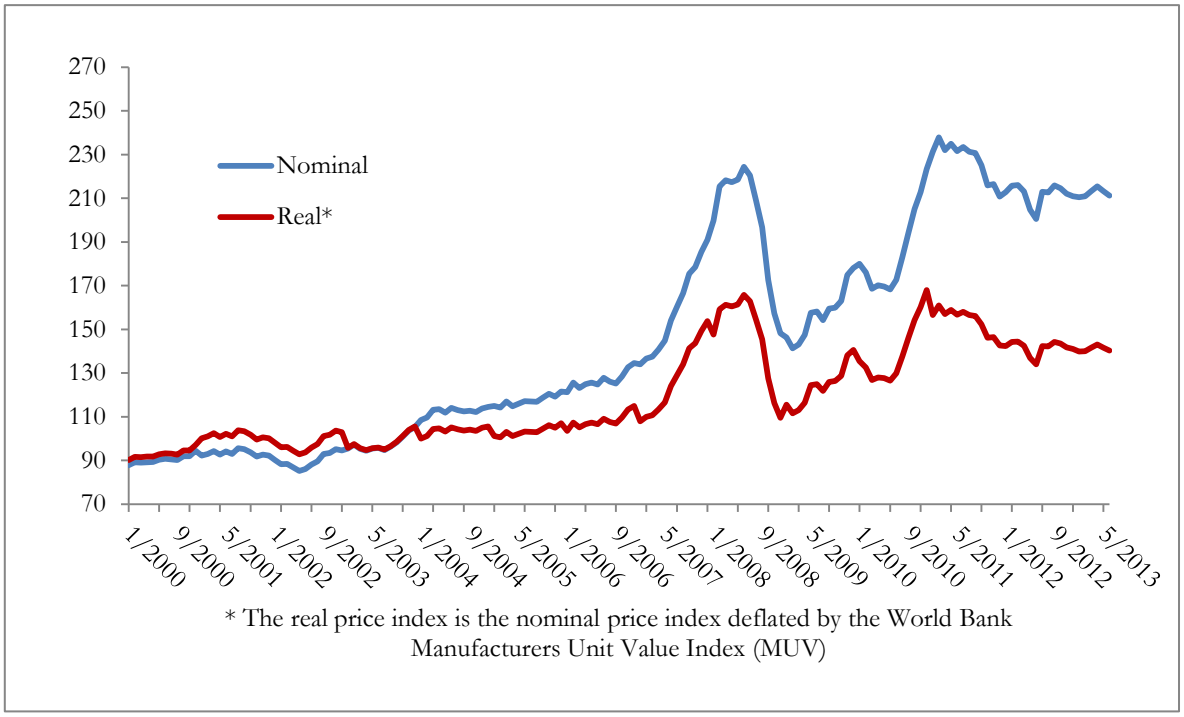


Figure 1 Monthly FAO food price index January 2000 to June 2013 (2002-2004 = 100). Source: (FAO 2013).

Many drivers of the recent 'price spikes' in food commodity markets have been put forth by researchers, NGOs (non-governmental organizations) and international organizations over the last five years. These studies address high and volatile food commodity prices from an aggregate level, leaving ample space to investigate the proposed causes and drivers on case specific and disaggregate scale.

One of the areas, which offer the opportunity to expand the knowledge on price behaviour, is the link between crude oil prices and the prices of animal feed used for livestock production in the European Union (EU). Livestock production is a high-input sector allocating large quantities of energy and food commodities in the form of animal feed as primary inputs for the production of livestock. Cereals and oilseeds that are used as animal feed in the production of livestock, are to a large extend the same commodities as the ones used for human consumption.

In 2012 EU farm animals were fed with approximately 472 million (mio.) tonnes of animal feed, 60% (forages and home-grown cereals) of this animal feed is produced on the farm itself and the other 40% (industrial compound feed and purchased straight feed stuffs) is purchased by famers on the animal feed market (FEFAC 2013). Figure 2 gives an overview of the exact composition of animal feed sourcing in the EU for 2012.

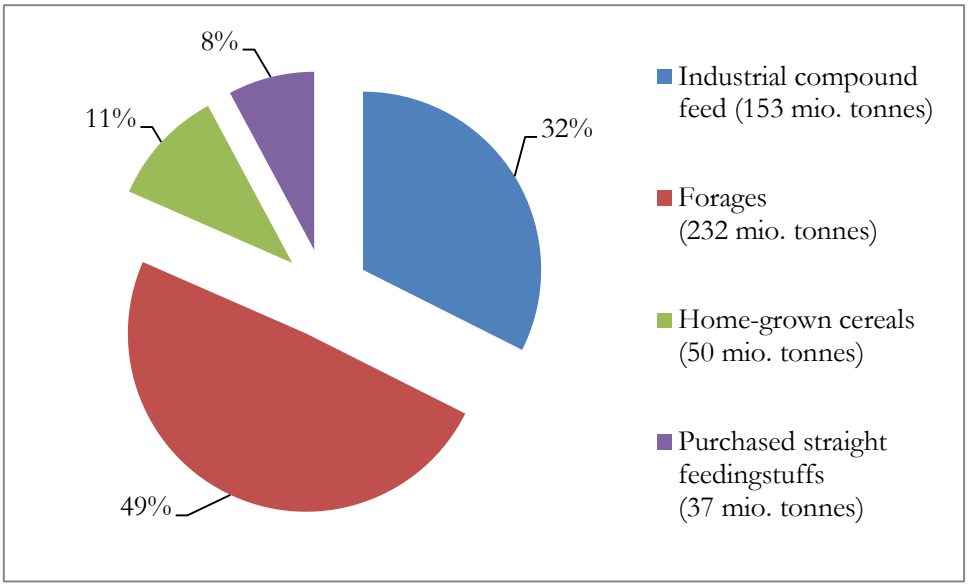


Figure 2 Animal feed sourcing EU-27 in 2012. Source: (FEFAC 2013).

Not only were livestock farmers faced with high and volatile animal feed prices, other input prices (e.g. of energy, transportation, and fertiliser) also increased due to their derived nature of crude oil as main input in production. This increase of input prices further pressured the gross margin livestock farmers receive for the animals they produce.

Thus, crude oil price fluctuations will be transmitted into food prices through the supply side of the food commodity market. Higher costs for inputs such as nitrogen-based fertiliser and transportation costs contribute to the transmission of crude oil price volatility into food commodity prices (Baffes 2007; Gilbert 2010; Mitchell 2008).

Not only supply is affected by crude oil price fluctuations, employment (Uri 1996) and the demand side of the market are affected as well. The advent of biofuels the last decade created a 'new' link between crude oil markets and food commodity markets, since several main staple foods (corn, wheat, oilseeds) can be used as feedstock for biofuels production. Biofuels are a close substitute for crude oil; implying high prices for crude oil may have increased the prices for food commodities (Baffes 2011; Du et al. 2011; Mitchell 2008).

1.2 Problem statement

During 2012, farmers in the EU derived 42% of total farm production value from livestock production (FEFAC 2013). Livestock sector specific characteristics are, among others, lagged and relatively long production cycles, energy intensive housing systems and the need for protein in animal feed production. High and volatile prices for crude oil and food commodities used as animal feed are a continued source of concern among stakeholders in the value chain. Volatile prices introduce an increased price risk for livestock farmers; these uncertain input prices can often not be transmitted into output prices for their outputs in the value chain and hamper decision-making and resource allocation within the sector. These market characteristics in combination with the tumultuous market circumstances over the last decade raise questions whether or not livestock farmers in the EU operate now in more volatile and riskier markets than a decade ago. Only few studies have considered price volatility in European livestock production. Serra (2011) investigates the impacts of a Bovine Spongiform Encephalopathy (BSE) outbreak on price volatility in the Spanish beef marketing chain; she finds increased levels of price volatility for producers during the BSE outbreak. Other studies investigate the effect of EU Common Agricultural Policy (CAP) reforms on price volatility in the Greek beef marketing chain or investigate price volatility in Greek broiler markets (Rezitis and Stavropoulos 2010; Rezitis and Stavropoulos 2011). The limited number of studies leaves ample space to further investigate price relations in European livestock farming.

1.3 Objective and research questions

General research objective:

Given the context described in the former sections this thesis aims to study price and price volatility linkages that might exist between crude oil prices and prices for selected animal feed commodities; feed cereals and oilseeds during the period of 1991 to 2013 in the EU-27.

This *general research* objective can be formulated in *specific research objectives*:

- Identify and create the relevant theoretical framework, through literature review, linking crude oil markets and animal feed markets in the EU.

- Design an empirical model, modelling price and price volatility linkages between crude oil markets and animal feed markets in the EU.

- Analyse price and price volatility linkages between crude oil markets and European animal feed markets.

1.4 Outline of report

The report is structured as follows. Chapter 2 provides an overview of the current market structure observed within the crude oil markets as well as the European animal feed market. It also describes direct and common oil/feed linkages found in the literature. In Chapter 3 the empirical data to investigate potential linkages is described. The following chapter, Chapter 4, offers the methodology with which the price relationships between the markets will be analysed. In Chapter 5 results are depicted and explained, ending the report with Chapters 6 and 7, in which firstly the study in this thesis is discussed and finally conclusions are drawn and future research is advised.

2 Market structure

Linking the world crude oil market with the European animal feed market starts by identifying and describing the main structure of the separate two markets. Section 2.1 presents a list of attributes that are used to describe the structure of both markets. In Sections 2.2 and 2.3 the general market structure of the world crude oil and the European animal feed market are presented, respectively. Finally, Section 2.4 gives an overview of how both markets are linked.

2.1 Common attributes of market structure

The formation of prices for both respective markets is primarily based on the market structure given by the market at hand. Nevertheless, as for most markets the prices and market behaviour of crude oil and animal feed are determined by common attributes of market structure, which include the following (Schnepf 2005):

- *The number of buyers and sellers* – more market participants are generally associated with increased price competitiveness.
- *The commodity's homogeneity in terms of type, variety, quality and end-use characteristics* – greater product differentiation is generally associated with greater price differences among products and markets.
- *The numbers of close substitutes* – the number of close substitutes influence the buyers' price sensitivity regarding the product at hand.
- *The commodity's storability* – greater storability gives the seller more options in terms of when and under what conditions to sell his products.
- *The transparency of price information* – greater transparency prevents price manipulation.
- *The ease of commodity transfer between buyers and sellers and among markets* – greater transparency prevents price manipulation.
- *Artificial restrictions on the market process, e.g. government policy or market collusion from a major participant* – more artificial restrictions tend to prevent the price from reaching its natural equilibrium level.

The points listed above will be used to describe the general market structure of the world crude oil market and the European animal feed market.

2.2 The world crude oil market

The generally accepted market structure for the world crude oil market is that of an oligopolistic market, in which a small group of producers produce the largest share of this resource and part of this production is orchestrated by the Organisation of the Petroleum Exporting Countries (OPEC), a multi-lateral cartel of oil producing countries[1]. All of its member states are highly dependent on oil exports, unified by their common interest in oil revenue maximisation. On average, petroleum exports represented 75% of the total exports of these countries in 2009. Aiming to sustain world demand for oil, OPEC has to balance market share and profits (Mileva and Siegfried 2012). OPEC's market power is derived from its share in global crude oil exports and proven reserves, which were respectively 60.4% and 81% in 2011 (OPEC 2012). In addition to OPEC's dominance in the world oil market, there is a diverse set of non-OPEC oil producing countries fulfilling the remaining world crude oil demand. Most OPEC oil is produced by 100% state owned companies, for example, the state-owned Saudi Aramco – which operates the largest conventional oil field in the world. Furthermore, not only producing countries take part in the production

[1] OPEC members as of 2014: Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates and Venezuela. Source: OPEC, 2014

and exploration of oil. In addition to these countries, the world oil market comprises of several large vertically integrated firms –the so called 'Oil majors' and various smaller firms (Mileva and Siegfried 2012).

The cost of producing a barrel of crude oil is a relative small percentage of the prices paid on spot- and futures markets ranging from USD 51.60 per barrel for United States off-shore produced oil to USD 16.88 per barrel of Middle East produced oil in 2009 (EIA 2014b), representing the differences in costs for exploration and capital investments needed for the actual production of a barrel of crude oil. Cost of storage differs as well between oil producing countries and oil consuming countries. Crude oil not produced is left in the ground at little to no costs. Meanwhile, oil-consuming countries cover the costs of storage and transportation (e.g. facilities, locked-in financial resources, etc.).

Different grades of crude oil are available, suited for different types of refineries. This sometimes results in a situation in which it is more economical for oil producing countries to export their domestic production and import a grade of crude oil suitable for refining in existing facilities. Another feature of the demand for crude oil is the lack of a short-term substitute for many of its uses, creating an inelastic demand curve (Cooper 2003).

Most of the world's crude oil trade takes place using a combination of term, spot and futures markets. Term contracts are estimated to account for just over 50% of global trade in crude oil (Energy Intelligence 2004). Although the spot market accounts for less than 50% of physical oil sales, spot prices are the primary determinant of almost all other petroleum prices. For example, they are used in most pricing formulas for the term crude oil sales of OPEC and many other producing countries (Energy Intelligence 2004). Many of the term and spot contracts traded are often confidential and thus function not as a proper mechanism for discovering crude oil prices.

For the last 30 years the development of crude oil futures contracts aided in the crude oil market becoming more transparent. In 1983 the New York Mercantile Exchange introduced the first crude oil futures contract, Light, Sweet Crude Oil, the most actively traded commodity derivative today (Mileva and Siegfried 2012). Different crude oil futures contracts are traded among several commodity exchanges, such as the International Petroleum Exchange (IPE) in London, the Tokyo Commodity Exchange (TOCOM) and the Multi Commodity Exchange of India (MCX). The trade in crude oil is mostly invoiced using U.S. dollars, although in recent years several examples of using other currencies than U.S. dollars have occurred. For example, Iran requested to settle oil exports to India using Euros (Kumar and Verma 2013).

Given its importance for the global economy, many governments and private interest groups try to influence the global oil market. The world oil market is also bounded by artificial restrictions, for example, oil-importing countries try to influence the petroleum market by fiscal instruments, anti-trust policies, public funds for alternative energy research or petroleum exploration activities, political intervention in situations in which the interests of the nation are at stake, environmental regulations and strategic oil reserves (Mileva and Siegfried 2012).

2.3 European animal feed market

Animal feed is one of the main inputs for livestock farming in general. As such the European animal feed market is the most important supply partner to this industry. Within the EU-27, approximately 472 mio. (see Figure 2) tonnes of animal feed were consumed by farm animals in 2012. About 280 mio. tonnes of feed are roughages and cereals grown and used on the farm of origin. The remaining 192 mio. tonnes

consist of feed purchased by livestock farmers to supplement their own feed resources, either feed materials or compound feed (FEFAC 2013).

Given this divide between 'home' grown and off-farm sourced animal feed the EU animal feed market can be divided into two segments: an 'informal' part – mainly consisting of on-farm grown forages and a 'formal' part in which trading and production of highly specialised compound feed is conducted by compound feed producers. With a total of 3812 production units for compound feed (FEFAC 2013) in the EU-27, operated mainly (85%) by SMEs (EUFETEC 2013), the animal feed market supply side can be viewed as a competitive market.

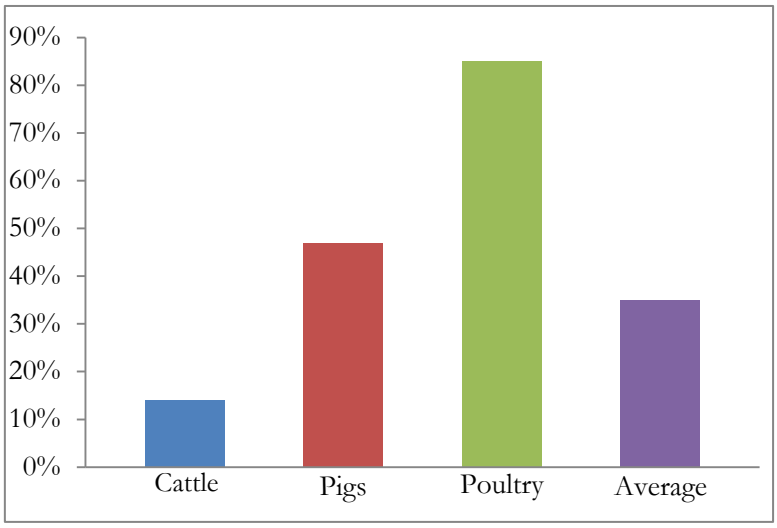


Figure 3 Value of purchased compound feed in total animal output value in 2011. Source: (FEFAC 2012)

In 2011, a total of 5 mio. farmers raised livestock with a total value of 165 billion Euros (Eurostat 2014). On average, the value of purchased animal feed is 35% of total animal output value, however, large differences occur between livestock sectors, see Figure 3.

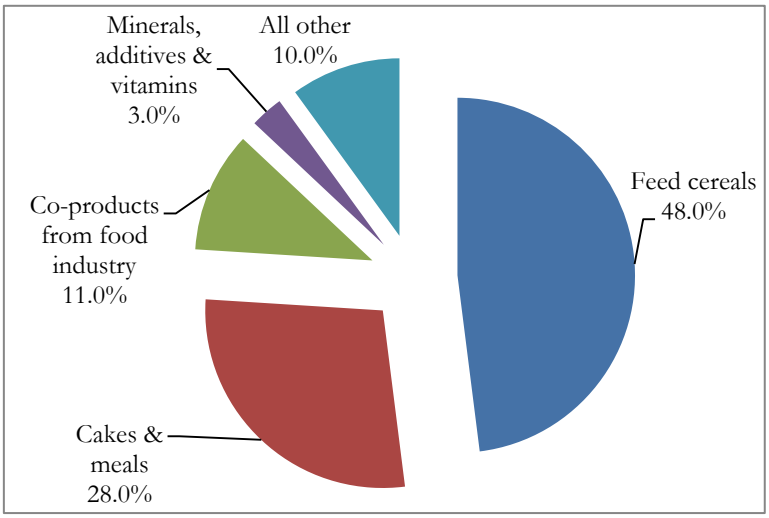


Figure 4 Feed material consumption by the compound feed industry in 2012, EU-27. Source: (FEFAC 2012).

Inputs used by the European animal feed industry can be found in Figure 4 primary source of inputs are feed cereals; oats, wheat, barley and rye consuming up to two-thirds of the annual cereal production in the EU-27 (EC 2014a). More than a quarter of inputs are cakes and meals, these are used as source of protein in animal feed and are soy- or rapeseed based, the former imported from outside the EU-27. Since animal feed is an essential input for the livestock sector, no substitutes are available. However, famers and the feed producing industry are able to differ the exact composition of the animal feed produced, for example by valorising more co-products from starch and ethanol industries or digestible fibre rich co-products from beet sugar industry and numerous liquid feeds (EUFETEC 2013).

Animal feed utilization falls under the legal framework of the EU's CAP. Its marketing, authorisation, supervision and labelling fall under different EU regulations. With respect to the EU's internal market some agricultural commodities used as animal feed inputs are eligible for the EU intervention scheme, which supports prices by setting a price guarantee for certain products. For example, the current intervention price for common EU wheat is €101.31 per tonne (EC 2011). The CAP's system of price support has prevented the forming of an extensive network of commodity exchanges within the EU. This lack of commodity exchanges makes it difficult to determine a unified price for the different animal feed stuffs. Next to this, another aspect which hinders the formation of transparent prices on the EU animal feed market is the processing and added value that compound feed producers add to raw materials.

Since the CAP reforms in 2003 many of the direct price support mechanisms previously used to support off-gate farm prices have been lowered or abolished. Thus far these reforms have not led to the widespread uptake of commodity exchanges in order to sell or purchase animal feed.

As in the case of crude oil, the storage of animal feed can be an intricate undertaking. Once stored, animal feed is subject to several threats such as insect infestation, microbiological contamination and chemical changes altering flavour and nutritional value. If not stored properly, these factors can affect the quality and health safety of animal feed potentially leading to severe economic losses (Chow 1978).

The market for animal feed crops, given its agricultural basis, has certain characteristics that differ from the market for crude oil; mainly the number of sellers and buyers in the market, storability, substitutes available in the market and seasonality of production. However, they do share common attributes: both are subject to government regulations and share price inelastic demand- and supply curves.

2.4 Market linkages

In linking crude oil and EU animal feed markets one can determine several factors influencing prices on both markets. These linkages can be divided in direct- and common linkages, by which prices on both markets are influenced. In the former case, prices on one market directly influence prices on the other market, whilst in the latter case macro fundamentals distort the price forming mechanism in both markets.

2.4.1 Direct oil/feed links

Crude oil prices directly influence the price on animal feed markets in the EU, because of the energy component in the production function of animal feed. Price behaviour within crude oil markets is channelled through the use of (i) fertiliser, which is produced using natural gas, a close substitute for crude oil, (ii) transportation of feed commodities, (iii) the use of oil-based chemical during growth stage and production processes and (vi) the costs associated with storing animal feed.

Another direct link between oil markets and animal feed markets is the advent of biofuel production the last decade. Main inputs for the production of biofuels (bioethanol and biodiesel) are inputs that are also used as animal feed. For example, the main input for EU biodiesel comes from rapeseed (Edwards et al. 2008). The use of biofuels (corn-based ethanol and biodiesel) as fuel for transportation makes it a close substitute for crude oil.

The use of biofuels and the link between markets for agricultural commodities and crude oil, have been subject of extensive study in the last decade. Tyner and Taheripour (2008a), using a partial equilibrium model, show that there is a link between agricultural and energy prices through biofuels and policies promoting their use. In another study by Tyner and Taheripour (2008b), using oil and corn price data from 1982-2007, they found a correlation between corn and oil prices of 0.16. Similar results were found by Abbott (2009), using price data of oil and corn prices from 1988-2008, finding an even stronger correlation between crude oil price and corn prices of 0.80 since 2006, also suggesting a link between crude oil markets and markets for agricultural commodities. The use of biofuel by-products in animal feed negatively influences the prices of animal feed as Taheripour et al. (2010) show in their study modelling the use of biofuel by-products through a general equilibrium framework.

2.4.2 Common oil/feed links

Common oil/feed links can be divided into three categories: (i) market fundamentals, (ii) macroeconomic factors, (iii) speculation.

Market fundamentals consist of supply and demand alterations, which are affected by common phenomena that affect the market for animal feed and crude oil simultaneously. A factor affecting the increased demand for goods from both markets is the unprecedented economic growth in the BRIC[2] countries, this increase in disposable income changes consumption patterns in these countries increasing demand for livestock and crude oil (Gilbert 2010; Kilian and Hicks 2013; Krichene 2008). Other market fundamentals, which can affect supply and demand, are exogenous market shocks (e.g. extreme weather conditions, labour strikes, animal diseases, etc.), creating 'price spikes', such as in 2007-2008 and 2011 within these markets (Abbott 2009; Baffes and Dennis 2013; Wright 2011). Low stock-to-use ratios have been put forth in explaining price behaviour in both markets for the last decade creating 'thin' markets, especially vulnerable for changes in supply and demand (Kesicki 2010; Wright 2011).

The most important macroeconomic factor affecting prices of animal feed and crude oil is the depreciation of the U.S. dollar against other currencies in the last decade (Abbott 2009; Baffes and Dennis 2013; Gilbert 2010; Headey and Fan 2008). The U.S. dollar is the global invoicing currency for both markets and the long-term depreciation of this currency affected exchange rates, which in turn caused markets to respond to these changes, causing prices nominated in U.S. dollar terms to rise (Lizardo and Mollick 2010; Reboredo 2012b).

Depreciation of the U.S. dollar combined with lose monetary policies in many countries, was the on-set for what commentators called the 'financialisation of commodities' – an inflow of 'new' money into commodity markets. This money found its way into commodity markets by means of index investment funds channelling money in commodities markets away from traditional investments such as stocks and bonds. Food commodity markets were also affected by this inflow of 'new' money, although the index

[2]BRIC countries consist of Brazil, Russia, India and China.

investment funds argument is still controversial in the literature. According to Gilbert (2010) around 43 per cent of the total changes in prices for food commodities can be contributed to index fund investment during the 2007-2008 'price spike'. Whilst other authors (Irwin and Sanders 2011; Irwin et al. 2009; Sanders and Irwin 2011) argue that there is no clear link between index investment funds activity in food commodity markets and increased price volatility in these markets, criticizing the methods and data used in the studies that do confirm a link between speculation and the 2007-2008 price boom. Several authors point to other forms of speculation as the main drivers (Baffes 2011; Cooke and Robles 2009; Gutierrez 2013). They argue that the inflow of 'new' money into food commodity markets may only have had short-term effects on food commodity prices, given the behaviour of the market's participants, money can quickly flow in or out of food commodity markets letting market fundamentals again determining prices (Baffes 2011; OECD 2008).

3 Data

This chapter provides a concise overview of the empirical data that will be employed in order to analyse potential linkages between crude oil prices and prices for selected animal feed commodities.

The data employed consists of monthly price series data from January 1991 to December 2013 (276 observations) for world oil prices and selected animal feed commodities, oats, wheat, maize, barley, rye and soybean meal, see Table 1 for more information.

Table 1 Price series data description.

Price Series	Label	Description	Unit	Source
Brent oil	$BOIL_P$	Europe Brent Spot Price FOB	U.S. $/barrel	Energy information Administration (EIA)
WTI oil	$WOIL_P$	West Texas Intermediate - Cushing, Oklahoma Spot Price FOB	U.S. $/barrel	Energy information Administration (EIA)
Feed Oats	FO_P	Feed oats, internal EU market price	€/metric ton	EU commission, Commodity Price Dashboard
Feed Wheat	FW_P	Feed wheat, internal EU market price	€/metric ton	EU commission, Commodity Price Dashboard
Feed Maize	FM_P	Feed Maize, internal EU market price	€/metric ton	EU commission, Commodity Price Dashboard
Feed Barley	FB_P	Feed Barley, internal EU market price	€/metric ton	EU commission, Commodity Price Dashboard
Feed Rye	FR_P	Feed Rye, internal EU market price	€/metric ton	EU commission, Commodity Price Dashboard
Soybean Meal	FSM_P	Soybean meal (any origin), Argentine 45/46% extraction, CIF Rotterdam	U.S. $/metric ton	World Bank, Global Economic Monitor (GEM) Commodities

By using price series ranging from January 1991 to December 2013 a period of relatively stable prices and the recent commodity price 'spikes' are captured. Not all prices are denominated in a single currency, therefore the choice is made to denominate all prices in €.

Within the price series several differences are observed. Prices for animal feed are internal European market prices, which could imply that given certain circumstances these prices were supported by intervention prices set by the CAP. For soybean meal prices, the series used for analysis include cost, insurance, freight (CIF), which could bring additional uncertainties since the costs of insurance and freight are very variable by itself. However, the costs for insurance and freight are only a small percentage of the original invoicing price, no large effects are expected. Finally, the prices for Brent and WTI oil are used as a proxy for the global crude oil market. Brent is a better predictor because of close proximity to the European market. The prices in this time series are spot prices free-on-board (FOB), meaning these prices do not include additional costs for insurance and transportation.

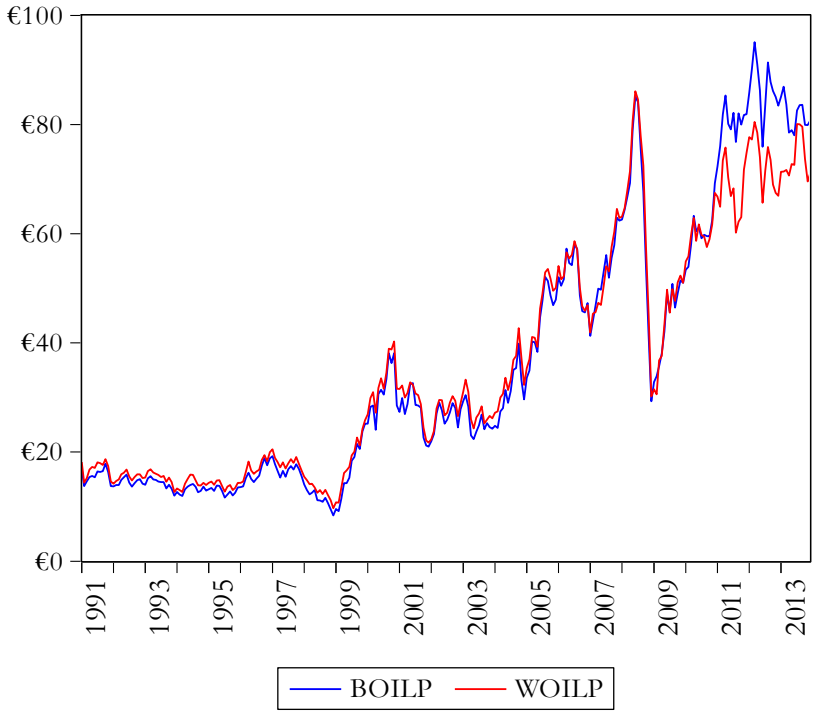


Figure 5 Nominal monthly crude oil prices for 1991 to 2013 in €/barrel. Source: (EIA; World Bank).

A first indication of potential trends and patterns in the price data is given by the graphical representation of the selected price data in Figure 5 and Figure 6.

Nominal monthly Brent- and WTI oil prices denoted in €/barrel can be found in Figure 5. The graph describes a reasonable tranquil price path between 1991 and 2000, between 2000 and 2007 a bullish price trend can be observed ending in the 2008-2009 financial crisis and subsequent economic downturn. Prices started to rise again in 2009 levelling off at around €85/barrel, which is the same price level reached just before the global financial crisis. Given the period under investigation the prices of Brent and WTI oil travel among the same path, however since 2010 both prices started to diverge.

Figure 6 shows the price path of all selected animal feed commodities. An interesting pattern occurs; the prices for European produced feed cereals appear to describe the same trend with a slightly bearish trend from 1991 to 2009. Prices started to increase in 2009 reaching to subsequent spikes in 2011 and 2012. In general, the prices for animal feed are characterised by price spikes. This price behaviour is clearly visible in the prices for soymeal (FSM_P), during the selected time window. These price 'peaks' in total 7 times indicating potential volatility in the price series. Individual graphs concerning all price series can be found in appendix A.

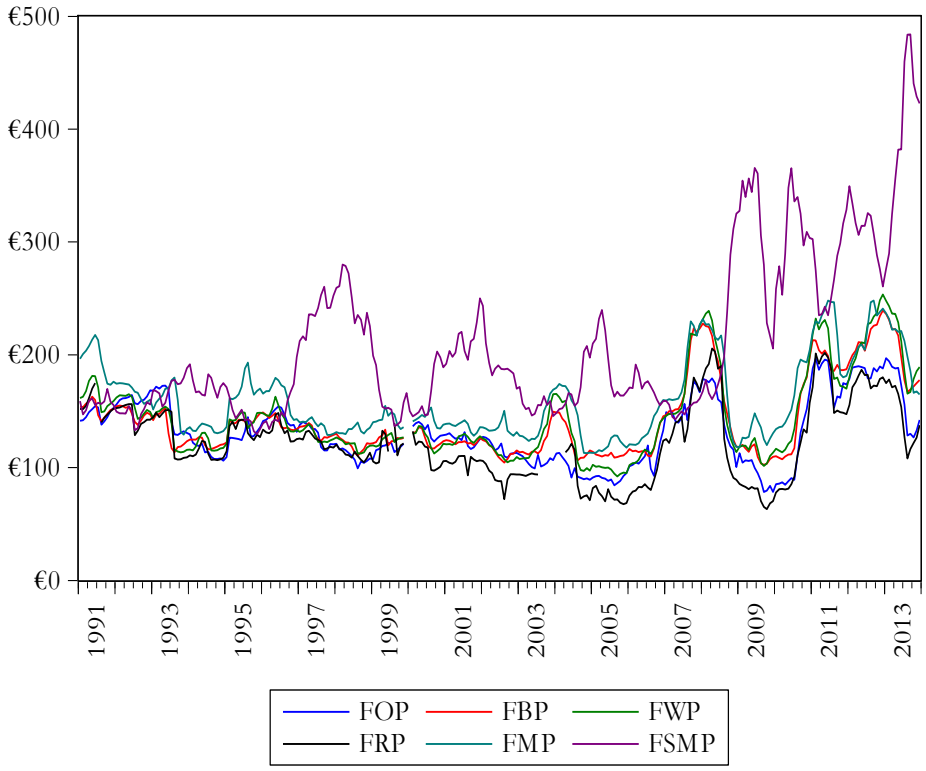


Figure 6 Nominal monthly prices for selected animal feed commodities for 1991 to 2013 in €/metric tonne. Source: (EC; World Bank).

A first step in relating the prices of both markets is reported in the correlation matrix, see Table 2, showing Pearson correlation coefficients in levels for all price series. It shows that both oil prices are correlated between 0.24 and 0.64 with animal feed commodities and that $WOIL_P$ has a slightly lower correlation than $BOIL_P$. In general, mutually animal feed commodities have relatively high correlation coefficients between 0.83 and 0.97, indicating a high integration of these markets. Exception on this pattern is FSM_P. This commodity seems to have a very low correlation with other feed commodities, for example, almost no relation to FR_P (0.01) can be found. However, the coefficients between $BOIL_P$, $WOIL_P$ and FSM_P do exhibit a relation with coefficients of 0.59 and 0.56, respectively. One important thing to note is that a correlation matrix does not give any indication of a casual relationships between variables.

Table 2 Correlation matrix of all commodities, period 1991-2013.

	$BOIL_P$	$WOIL_P$	FO_P	FW_P	FM_P	FB_P	FR_P	FSM_P
$BOIL_P$	1							
$WOIL_P$	0.989	1						
FO_P	0.381	0.308	1					
FW_P	0.603	0.5426	0.879	1				
FM_P	0.563	0.504	0.830	0.944	1			
FB_P	0.647	0.587	0.876	0.980	0.917	1		
FR_P	0.316	0.247	0.919	0.898	0.8706	0.871	1	
FSM_P	0.592	0.562	0.0864	0.268	0.192	0.2854	0.014	1

Table 3 Descriptive statistics of all employed price series, 1991 to 2013.

	$BOIL_P$	$WOIL_P$	FO_P	FW_P	FM_P	FB_P	FR_P	FSM_P
Mean	36.463	36.537	131.201	143.793	159.756	142.260	122.577	211.465
Maximum	95.091	86.085	196.880	253.472	248.151	239.160	205.498	483.854
Minimum	8.386	9.6929	78.370	92.289	112.889	102.483	63.295	129.630
Std. Dev.	24.436	21.7969	29.385	38.160	34.9140	34.175	33.148	72.699
Skewness	0.824	0.568	0.441	1.158	0.908	1.240	0.4140	1.357
Kurtosis	2.379	1.942	2.374	3.483	2.776	3.497	2.533	4.456
Jarque-Bera	31.505	26.540	11.650	61.543	36.789	70.330	9.941	104.322
p-value	0.000	0.000	0.002	0.000	0.000	0.000	0.006	0.000
# observations	276	276	274	274	274	274	264	276

Final step in describing the data is provided in Table 3 in which the descriptive statistics of the data employed are presented. Interesting point to notice is that the means for both, the crude oil and the animal feed markets lie relatively close to each other within their respective markets. However, again FSM_P has a different profile than the other commodities in the animal feed market. Both the mean (211.465) and the std. dev. (72.699) are considerably higher as well as the kurtosis (4.456), which is highest of all commodities considered. Throughout the data at hand deviating values of skewness ($\neq 0$) and kurtosis ($\neq 3$) are observed, indicating potentially non-normal distributed data and a high probability of extreme values. Additionally, the Jarque-Bera test statistic rejects normal distribution of the data for all time series employed.

An important aspect of this thesis are price volatility linkages between the respective markets; therefore the aspect of volatility is an important part of the data. Volatility can be derived from the first difference of a series with variable Y:

$$\Delta Y_t = Y_t - Y_{t-1} \tag{1}$$

and offers a clear picture of price volatility as far as these price changes are unexpected. Ultimately, price volatility is defined as the variance in the unexpected price changes.

Figure 7 presents a preliminary insight in the price series for Brent and WTI oil from a first difference perspective. This monthly price change corresponds to a large extend with Figure 5. During the period from 1991 to 2000 the price volatility describes a narrow band around zero. This behaviour started to change after 2000 with increasingly larger monthly price changes. Around 2008-2009 a depression in the monthly price changes occurs, with a rebound to what seems the same price behaviour as in the period 2000 to 2007. Interesting point to notice is that, although prices for Brent and WTI diverge since 2010, their volatility behaviour do look the same.

A similar transformation on the price series for selected animal feed commodities can be found in Figure 8. Most commodities seem to behave in a similar fashion. However the prices for FSM_P (D_FSMP) exhibit extreme behaviour, with very large positive and negative values compared to the prices of the other commodities. This could imply an increase in volatility by unexpected price changes since 2007 for FSM_P.

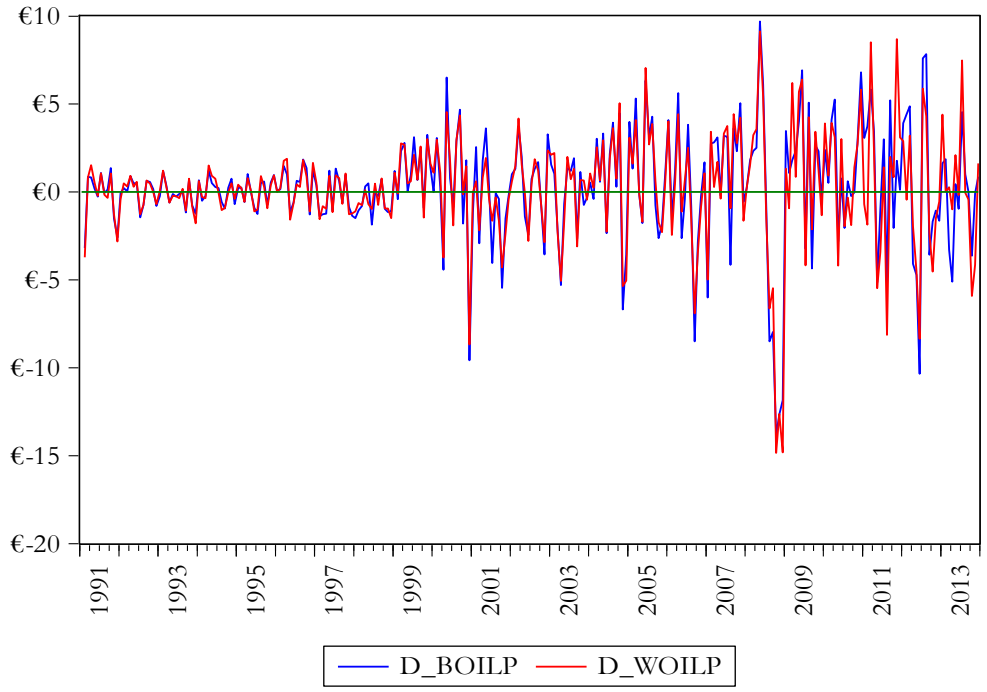


Figure 7 Monthly price volatility crude oil prices for 1991 to 2013. Source: Author's own work based on (EIA; World Bank).

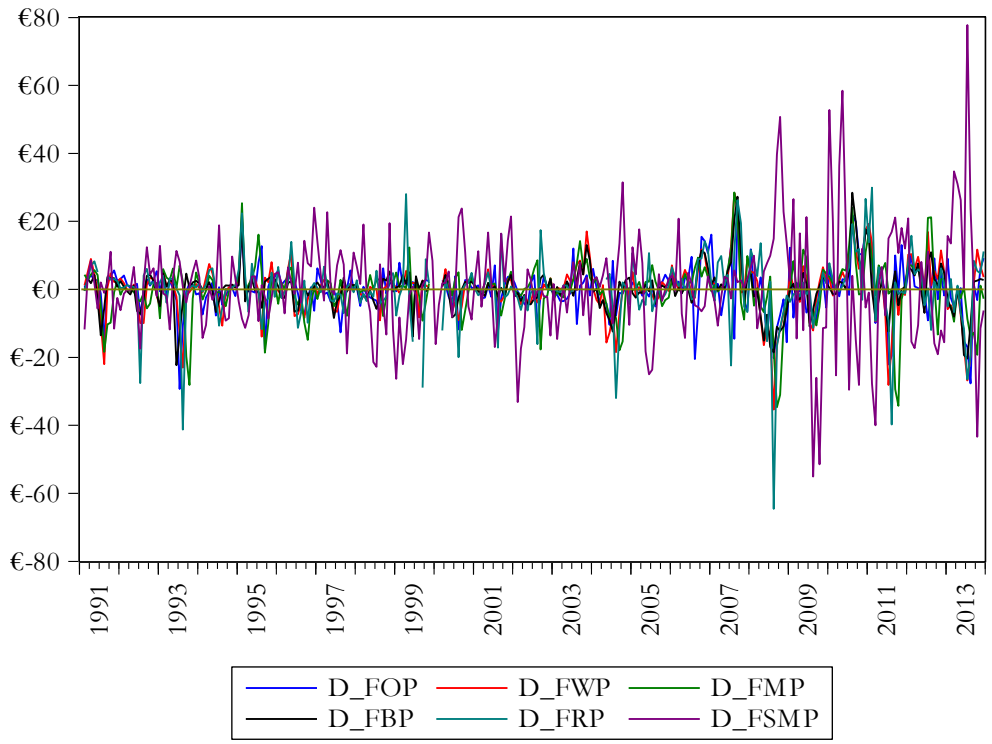


Figure 8 Monthly price volatility selected animal feed commodities for 1991 to 2013. Source: Author's own work based on (EC; World Bank 2014).

Table 4 Coefficients of variation all employed price series in multiple periods.

Period	$BOIL_P$	$WOIL_P$	FO_P	FW_P	FM_P	FB_P	FR_P	FSM_P
1991M1-2013M12	0.751	0.717	0.224	0.261	0.215	0.237	0.270	0.406
1991M1-1998M12	0.161	0.148	0.143	0.129	0.147	0.097	0.131	0.157
1999M1-2006M12	0.454	0.431	0.131	0.138	0.108	0.085	0.181	0.185
2007M1-2013M12	0.254	0.224	0.254	0.256	0.214	0.244	0.304	0.282

Before the investigation of price linkages, Table 4 offers a preliminary and intuitive insight in the price series volatility for the period under investigation. The coefficient of variation (CV) shows the volatility of the price series around its mean. Although this method is rather coarse and easily flawed (e.g. it does not account for seasonality) it does provide several interesting observations. For the whole period $BOIL_P$ and $WOIL_P$ exhibit the highest CV, this however, can be explained by its low mean compared to the standard deviation for the given period. The CV for feed commodities is relatively low between 0.215 to 0.270, indicating low monthly price volatility and although FSM_P has a higher CV of 0.406, looking at the three sub periods defined FSM_P, its price volatility does behave in a similar way. In general, the price series do behave relatively similar for all sub periods. The first two periods exhibit relatively low values of CV with exception of $BOIL_P$ and $WOIL_P$, which have a large increase of CV in the middle period. Finally all prices undergo an increase of CV in the final period.

Chapter 3 has revealed several indications that support further investigation of price linkages between the two respective markets. A visual inspection supports the notion of increased price variation seen in crude oil prices as well as animal feed prices for the last decade. Especially investigating the first differences within the respective periods points to an increased volatility in recent years. This notion of increased volatility is confirmed by calculating simple CV for the data. Finding relations between both markets, the correlation matrix given in Table 2 provides a starting point by showing relatively high correlation coefficients between oil markets and animal feed markets. Given the characteristics of the data, abnormal levels of skewness and kurtosis, the use of more advanced techniques is justified in order to investigate linkages between crude oil markets and European animal feed markets in price levels and volatility.

4 Methodology

This chapter places apart the methodology followed for investigating the research objectives. According to Myers (1994) time series econometrics for commodity price analysis has to deal with several properties of the underlying series: (i) high volatility, (ii) stochastic trends, (iii) comovement in commodity price series and (iv) time-varying volatility. In order to correctly investigate the research objectives the methodology proposed will focus on stochastic trends in the data and comovement among commodity price series.

Section 4.1 deals with the unit root test, Section 4.2 describes the Two-Step Engle-Granger and Johansen cointegration tests investigating comovement between price series. Finally, Section 4.3 outlines the methodology followed for testing Granger causality investigating price level and price volatility linkages.

4.1 Unit root

Commodity price time series are often unit root non-stationary, i.e., within the data there is a stochastic trend present. A series is assumed to be non-stationary if it has a non-constant mean and/or non-constant variance and autocovariance over time. The stochastic trend has the ability to impair the analysis by creating spurious regressions of the OLS estimators. First described by Granger and Newbold (1974), this incorrect interpretation of OLS estimates can lead to misleading results. The tests for unit root will aid in specifying the correct models used later on in this thesis.

4.1.1 Augmented Dickey-Fuller test

The most well-known test for a unit root in a time series is the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller 1979; Said and Dickey 1984). The ADF test statistic for variable Y_t is given in equation (2):

$$\Delta Y_t = \alpha + \beta t + \delta Y_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta Y_{t-i} + \varepsilon_t \tag{2}$$

where Y_t is the series under investigation, α is a constant, β is the trend coefficient, p is the number of lagged differenced terms and ε_t is the error term. Ignoring the lagged differenced terms for ease of demonstration, three different ADF test equations can be considered on the basis of the deterministic specification:

Y_t is a random walk: $\Delta Y_t = \delta Y_{t-1} + \varepsilon_t$

Y_t is a random walk with drift: $\Delta Y_t = \alpha + \delta Y_{t-1} + \varepsilon_t$

Y_t is a random walk with drift around a deterministic trend: $\Delta Y_t = \alpha + \beta t + \delta Y_{t-1} + \varepsilon_t$

For each model, the null hypothesis is $\delta = 0$. The alternative hypothesis is that the time series is stationary, or that $\delta < 0$. The one-sided critical values are based on MacKinnon (1996) and differ between the three deterministic models. Rejecting the null hypothesis for the first model means that Y_t is stationary with mean zero. In the second model rejecting the null hypothesis implies that Y_t is stationary with a nonzero mean. If the null hypothesis is rejected for the third model, it means that Y_t is stationary around a deterministic trend. Looking at the time series graph as well as some descriptive data like the mean, then if the time series in levels has a constant close to zero, the first model is used in the ADF procedure. A constant clearly different from zero advocates the second model and the third model is used if the time series exhibits a trend. Order selection criteria like the Schwartz Criterion are applied to determine the lag length *p* in (2).

Using the procedure described above, all price series will be tested for a unit root in levels. Given the specific characteristics of price data time series, one would expect them to contain a unit root. Taking this assumption into account, the price series have to be differenced once to become stationary. In that case, it is said that the price series in levels is integrated of order 1, denoted *I*(1), and hence, the series in first differences is integrated of order zero, denoted *I*(0). Of course, the ADF test can also be applied on the first-differenced series to check whether the unit root should be rejected.

4.2 Cointegration

The second step in analysing relationships between crude oil markets and the European animal feed market is finding whether or not there exists a long-term price relationship between them. Assuming the data is non-stationary in levels, one could imagine that a linear combination of two variables has a stationary equilibrium stating that the series are cointegrated. In case of cointegration they share a common stochastic trend, for example caused by common market forces. To investigate this long-term relationship, a bi-variate price relationship between the Brent oil and each of the selected feed commodity prices will be estimated employing both the Engle-Granger Two-step and Johansen cointegration tests. Using two different cointegration test techniques will increase the robustness of the results.

4.2.1 Two-step Engle-Granger cointegration test

In their seminal paper on cointegration Engle and Granger (1987) devised a method to determine whether two variables are co-integrated. After finding the series to be integrated of the same order *I(1)*, the second step is to run an OLS regression as follows:

$$Y_t = \alpha + \beta X_t + \varepsilon_t \tag{3}$$

In which Y_t and X_t are the non-stationary price series under investigation. Next step is to estimate the residual error ε_t and test, using an ADF test for a unit root, whether or not ε_t is stationary. This ADF test takes on the following from:

$$\Delta\hat{\varepsilon}_t = \beta\hat{\varepsilon}_{t-1} + \sum_{i=1}^{p} \Delta\,\hat{\varepsilon}_{t-i} + \mu_t \tag{4}$$

Looking for a unit root in the residuals of a first-stage OLS on non-stationary series implies that one cannot use t-distributed critical values. Given the asymptotic distribution of the test statistic, Davidson and MacKinnon (1993) suggest using other critical values which better suit the underlying distribution of the error terms. The hypothesis for this test tests for no-cointegration, so rejecting H_0, would imply that cointegration is present among the variables under investigation.

4.2.2 Johansen cointegration test

Another approach for investigating cointegration between variables was proposed by Johansen (1991). The method determines the amount of cointegration vectors of non-stationary price series using a Vector autoregression (VAR) model of order *p*. This model can be defined as

$$\Delta Y_t = \mu + \sum_{i=1}^{p-1} \Pi_i\, \Delta Y_{t-i} + \alpha\beta' Y_{t-1} + \varepsilon_t \tag{5}$$

Where Y_t is an (n x 1) vector representing the n market prices for crude oil or animal feed, Π_i is an (n x n) matrices of coefficients, α is an (n x r) matrix of error correction coefficients and β is an (n x r) matrix of r cointegrating vectors, so that 0 < r < n, representing the coefficients in the long-run cointegrating

relationship between the variables such that $\beta' Y_t$ are the deviations from the long-run price equilibrium that are error-corrected by the error-correction terms $\alpha\beta' Y_{t-1}$ in (5).

In other words, Johansen tests for the rank of the matrix, which in the bi-variate case is expected to be 1 in case of cointegration between the variables. A rank of 2 implies that both series are already stationary and a matrix of rank 0 means that there is no common stochastic trend present.

In defining the correct lag length p for the VAR the Schwarz Information Criterion (SIC) is used for selecting the optimal lag length. SIC provides a relatively conservative estimation for the optimal lag length preventing the model from over fitting through a too large number of lags.

Johansen (1991) suggests two different test statistics (Trace test and Maximum Eigen Value test) for testing the hypothesis of cointegration within the variables under investigation: (i) The test for Maximum Eigenvalue, which tests each eigenvalue separately. It tests the null hypothesis: number of cointegrating vectors = r against the alternative hypothesis that the system has r+1 cointegrating vectors. (ii). The Trace test investigates whether the null hypothesis of no cointegration, the rank of the matrix is zero, against the alternative hypothesis of cointegration, indicating the rank of the matrix is larger than zero.

4.3 Granger causality

The two methodologies proposed for cointegration testing, Engle-Granger and Johansen, both suggest that there exists a long-term common stochastic trend on finding cointegration in our bi-variate samples. However, if no cointegration is found, it is still possible to test whether or not the samples exhibit simultaneous behaviour. According to the concept of Granger causality a bi-variate VAR consisting of the series Y_t and X_t exhibits Granger causality of Y_t to X_t, if the lagged values of Y_t improves the estimation of X_t. This causality in the sense of Granger suggests some lead-lag behaviour in the bi-variate sample, even without the indication of a long-term cointegration vector.

4.3.1 Granger causality testing

Testing potential causality between crude oil markets and European animal feed markets will be done by employing a bi-variate VAR model representing both price series. By estimating the following VAR model the bi-variate series will be tested for absence of Granger causality:

$$Y_t = a_0 + a_1 Y_{t-1} + \cdots + a_p Y_{t-p} + b_1 X_{t-1} + \cdots + b_p X_{t-p} + \varepsilon_t \tag{6}$$

$$X_t = c_0 + c_1 X_{t-1} + \cdots + c_p X_{t-p} + d_1 Y_{t-1} + \cdots + d_p Y_{t-p} + \varepsilon_t \tag{7}$$

Since testing for causality in the sense of Granger implies that the lagged values of X_t improves the forecast of Y_t and vice versa, the following hypothesis are tested

$$H_0\text{: } b_1 = b_2 = \cdots = b_p = 0 \mid H_a\text{: 'not } H_0\text{'}$$

Rejecting H_0 implies that X_t Granger causes Y_t.

$$H_0\text{: } d_1 = d_2 = \cdots = d_p = 0 \mid H_a\text{: 'not } H_0\text{'}$$

Rejecting H_0 implies that Y_t Granger causes X_t.

The first step of testing Granger causality will be conducted with the price series in first differences and, if cointegration is found, error-correction terms will be included in the model, reflecting direct price linkages

in levels between the data. The quadratic values of the residuals of these VARs are modelled again by a bi-variate VAR to test for Granger causality, thus reflecting any price volatility linkages between crude oil markets and European animal feed markets.

For choosing the correct number of lags to include in the model, again information criteria based on SIC is used.

5 Results

Chapter 5 provides an overview of the main results based on the analysis conducted. The methodology proposed in Chapter 4 was followed in attaining these results. Section 5.1 deals with the results of unit root tests. In Section 5.2 Engle-Granger and Johansen tests for cointegration are shown. Section 5.3 discusses the Granger causality tests.

After a further visual inspection, two sub periods: 1991M1-2001M12 and 2002M1-2013M12 were selected. Furthermore, Brent Oil ($BOIL_P$) was chosen to function as a proxy for the crude oil market. The latter choice is based on the similarities between the $WOIL_P$ and $BOIL_P$ price series and the convenience of working with one crude oil price series.

All results are expressed in natural logarithms reducing the impact of potential outliers and letting the coefficient estimates being interpreted as elasticities.

5.1 Unit root

Following the ADF methodology described in Chapter 4 all price series were tested in levels and first differences in order to determine the order of integration. From the methodology the first specification (without any deterministic terms) proposed was used in testing for unit root. This specification was used for the whole sample as well as the 2 sub-periods.

The results in Table 5 show that all price series are non-stationary in levels and all price series are stationary in first differences. The pre-testing for a unit root using, the ADF test and identifying that the data are integrated of order one, I(1), justifies the use of cointegration methods for investigating long term price relationships between crude oil markets and European animal feed markets.

Table 5 ADF results for all price series.

Period	**1991M1-2013M12**	**1991M1-2001M12**	**2002M1-2013M12**
	Test Statistic	Test Statistic	Test Statistic
$LnBOIL_P$	0.95	0.003	1.172
$\Delta LnBOIL_P$	-14.587*	-5.112*	-5.947*
$LnFO_P$	-0.209	-0.573	0.043
$\Delta LnFO_P$	-3.793*	-9.945*	-2.984*
$LnFW_P$	-0.054	-0.49	0.138
$\Delta LnFW_P$	-8.954*	-7.910*	-5.666*
$LnFM_P$	-0.358	-0.948	0.031
$\Delta LnFM_P$	-9.804*	-8.124*	-5.378*
$LnFB_P$	-0.02	-0.656	0.123
$\Delta LnFB_P$	-9.096*	-8.694*	-4.274*
$LnFR_P$	-0.153	-0.812	-0.09
$\Delta LnFR_P$	-13.473*	-5.498*	-8.628*
$LnFSM_P$	0.627	0.572	0.285
$\Delta LnFSM_P$	-11.757*	-5.942*	-8.125*

Note: optimal lag length determined by Schwarz Information Criterion (SIC). * denotes critical values larger than 5% significance level -1.942 based on MacKinnon (1996).

5.2 Cointegration

After finding that all price series are stationary in first differences, the next step in the methodology proposed is testing for cointegration. Aim of this procedure is finding a common stochastic trend which could imply that there is a large force influencing both series. The following section provides an overview of the results for testing cointegration in a bi-variate setting using the method proposed by Engle-Granger (5.2.1) and Johansen (5.2.2)

5.2.1 Two-step Engle-Granger cointegration test

The results of testing for cointegration using Engle-Granger can be found in Table 6. As discussed in the methodology the results are derived from testing the estimated residuals of an OLS regression in which commodity X_t was regressed on the crude oil variable Y_t. The OLS residuals were tested for a unit root using the ADF test.

The findings show that there is no long-term relationship between crude oil and oats, rye and soy meal for all periods under investigation. The relationship between crude oil and wheat, maize and barley is not that clear, cointegration is found for the whole sample (1991M1-2013M12), however, it is rejected for both subsamples. A further visual inspection of the results is therefore at its place.

Table 6 Results two-step Engle-Granger cointegration test.

	1991M1-2013M12		**1991M1-2001M12**		**2002M1-2013M12**	
$LnBOIL_P$ *vs*	Test Statistic	Cointegrated	Test Statistic	Cointegrated	Test Statistic	Cointegrated
$LnFO_P$	-2.503	No	-1.703892	No	-2.655524	No
$LnFW_P$	-3.493*	Yes	-2.942834	No	-3.090664	No
$LnFM_P$	-3.812*	Yes	-2.869113	No	-2.896381	No
$LnFB_P$	-3.356*	Yes	-2.936226	No	-3.125421	No
$LnFR_P$	-2.543	No	-2.532873	No	-2.962724	No
$LnFSM_P$	-3.002	No	-1.759676	No	-2.566661	No

Note: using the critical values by Davidson and MacKinnon (1993), with 2 variables in the model * denotes values larger than 5% significance level -3.34.

Rejecting the null hypothesis for the ADF test suggests that the estimated OLS residuals are stationary meaning that the two prices in the OLS regression are cointegrated. After inspection of Figures 9 to 11, however, the residuals clearly show the absence of a stationary mean and variance, preliminary concluding that in spite of the ADF test results the residuals are not stationary at all and hence, that there is no cointergration between crude oil and wheat, maize and barley. The results of Engle-Granger will be validated using Johansen cointegration test.

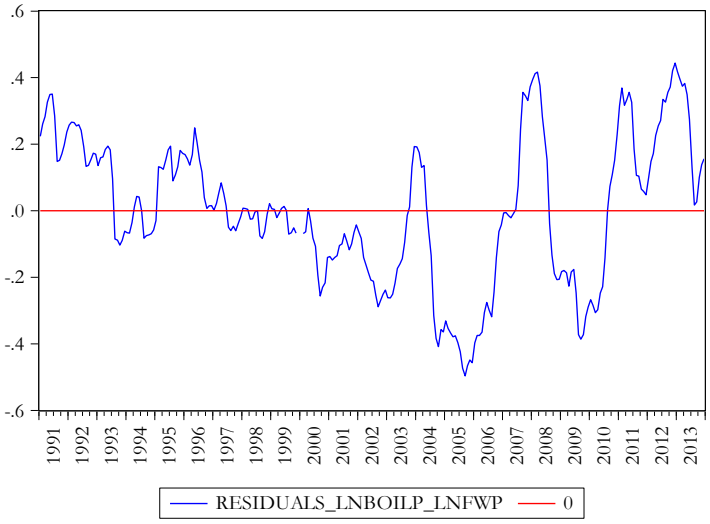


Figure 9 Residuals crude oil and feed wheat.

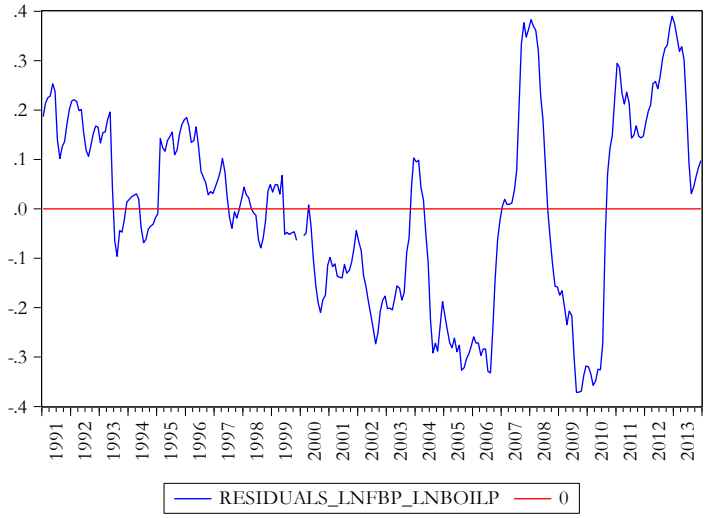


Figure 10 Residuals crude oil and feed barley.

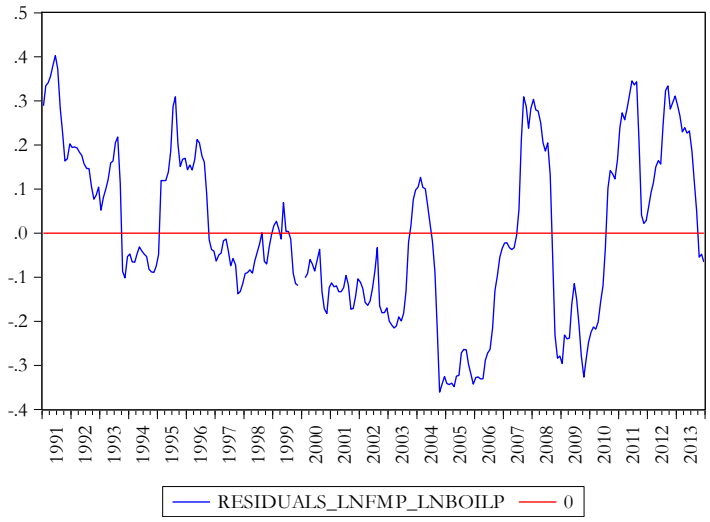


Figure 11 Residuals crude oil and feed maize.

5.2.2 Johansen cointegration tests

The Johansen cointegration tests depicted in Table 7 and Table 8 provide an overview of testing for a common stochastic trend using the methodology described in Chapter 4.

For the complete sample (Table 7), no long-term price relationship between crude oil and animal feed is found. Applying the same procedure on the two sub periods (Table 8) all bi-variate VARs reject cointegration, with the exception of crude oil and soy meal during the period 1991M1-2001M12. However, given the fact that the probability of the test statistic (= 0.035) is higher than 2.5%, that cointegration for the whole sample is rejected and that the two-step Engle-Granger test rejects cointegration between the two variables, also for this case it is still concluded that there is no cointegration.

By employing two different methods to test for a long-term relationship and the clear results that reject the presence of such a relationship in the bi-variate case, the next step of the analysis can commence. The next step will be to search for possible short-term price relationships between crude oil markets and the European animal feed markets.

Table 7 Results Johansen cointegration tests 1991-2013.

Period	**1991M1-2013M12**	
$LnBOIL_P$ vs	Test Statistic (Trace)	Decision
$LnFO_P$		
(AIC: 2 | SIC: 2)		
H_0: r=0 vs H_a: r > =1	8.564 [0.776]	Not rejected
H_0: r =<1 vs H_a: r >=2	-	-
$LnFW_P$		
(AIC: 2 | SIC: 2)		
H_0: r=0 vs H_a: r > =1	14.363 [0.265]	Not rejected
H_0: r =<1 vs H_a: r >=2	-	-
$LnFM_P$		
(AIC: 3 | SIC: 2)**		
H_0: r=0 vs H_a: r > =1	17.039 [0.131]	Not rejected
H_0: r =<1 vs H_a: r >=2	-	-
$LnFB_P$		
(AIC: 2 | SIC: 2)		
H_0: r=0 vs H_a: r > =1	13.516 [0.324]	Not rejected
H_0: r =<1 vs H_a: r >=2	-	-
$LnFR_P$		
(AIC: 2 | SIC: 2)		
H_0: r=0 vs H_a: r > =1	7.407 [0.870]	Not rejected
H_0: r =<1 vs H_a: r >=2	-	-
$LnFSM_P$		
(AIC: 3 | SIC: 2)**		
H_0: r=0 vs H_a: r > =1	15.454 [0.202]	Not rejected
H_0: r =<1 vs H_a: r >=2	-	-

Note: using the critical values byMackinnon et al. (1999)* denotes values larger than 5% significance level - 20.262. ** is the optimal lag length selected by using SIC.

Table 8 Results Johansen cointegration tests 1991-2001 and 2002-2013.

Period	**1991M1-2001M12**		**2002M1-2013M12**		
$LnBOIL_P$ vs	Test Statistic (Trace)	Decision	$LnBOIL_P$ vs	Test Statistic (Trace)	Decision
$LnFO_P$			$LnFO_P$		
(AIC: 1 | SIC: 1)			**(AIC: 2 | SIC: 2)**		
H_0: r=0 vs H_a: r > =1	6.604	Not rejected	H_0: r=0 vs H_a: r > =1	12.059	Not rejected
	[0.921]			[0.444]	
H_0: r =<1 vs H_a: r >=2	-	-	H_0: r =<1 vs H_a: r >=2	-	-
$LnFW_P$			$LnFW_P$		
(AIC: 2 | SIC: 1)**			**(AIC: 2 | SIC: 2)**		
H_0: r=0 vs H_a: r > =1	8.195	Not rejected	H_0: r=0 vs H_a: r > =1	16.216	Not rejected
	[0.808]			[0.165]	
H_0: r =<1 vs H_a: r >=2	-	-	H_0: r =<1 vs H_a: r >=2	-	-
$LnFM_P$			$LnFM_P$		
(AIC: 2 | SIC: 1)**			**(AIC: 2 | SIC: 2)**		
H_0: r=0 vs H_a: r > =1	10.599	Not rejected	H_0: r=0 vs H_a: r > =1	15.319	Not rejected
	[0.581]			[0.209]	
H_0: r =<1 vs H_a: r >=2	-	-	H_0: r =<1 vs H_a: r >=2	-	-
$LnFB_P$			$LnFB_P$		
(AIC: 2 | SIC: 1)**			**(AIC: 4 | SIC: 2**)**		
H_0: r=0 vs H_a: r > =1	9.252	Not rejected	H_0: r=0 vs H_a: r > =1	17.451	Not rejected
	[0.713]			[0.117]	
H_0: r =<1 vs H_a: r >=2	-	-	H_0: r =<1 vs H_a: r >=2	-	-
$LnFR_P$			$LnFR_P$		
(AIC: 1 | SIC: 1)			**(AIC: 4 | SIC: 2**)**		
H_0: r=0 vs H_a: r > =1	10.211	Not rejected	H_0: r=0 vs H_a: r > =1	13.576	Not rejected
	[0.619]			[0.320]	
H_0: r =<1 vs H_a: r >=2	-	-	H_0: r =<1 vs H_a: r >=2	-	-
$LnFSM_P$			$LnFSM_P$		
(AIC: 3 | SIC: 1)**			**(AIC: 2 | SIC: 2)**		
H_0: r=0 vs H_a: r > =1	**21.415***	**Rejected**	H_0: r=0 vs H_a: r > =1	14.578	Not rejected
	[0.035]			[0.252]	
H_0: r =<1 vs H_a: r >=2	8.608	Not rejected	H_0: r =<1 vs H_a: r >=2	-	-
	[0.064]				

Note: using the critical values byMackinnon et al. (1999)* denotes values larger than 5% significance level - 20.262. ** is the optimal lag length selected by using SIC.

5.3 Granger causality

5.3.1 Granger causality in levels

A first step in analysing whether or not a dynamic relationship is present between crude oil markets and European animal feed markets is testing for Granger causality in prices for all the three samples. As no cointegration was found between the animal feed commodity prices and the crude oil price, while the prices of both markets were tested to be integrated of order one, efficient Granger causality test results are obtained by considering VARs in first differences. Summarising the results of the Granger causality tests in Table 9, Table 10 and Table 11 show that a causal relationship between crude oil and the selected animal feed commodities primarily run from animal feed to crude oil. This implies that prices of animal feed commodities can improve the price prediction of crude oil for the periods under investigation.

Looking at the whole sample (Table 9), a causal relationship between maize, soy meal and crude oil is found. During the first sub period (Table 10) no Granger causality is detected. The dynamics between crude oil and animal feed mainly focus on the last sub period found in (Table 11). This period reveals causal relationships between maize and feed soy meal on the one hand and crude oil on the other. For feed oats, the reverse causal inference is found, where crude oil Granger causes the prices for this commodity.

Table 9 Results Granger causality tests in levels, 1991-2013.

Period 1991M1-2013M12	Hypothesis	Test statistic (χ^2)	Granger causality
$LnBOIL_P$ & $LnFO_P$	H_0: $LnFO_P$ does not Granger cause $LnBOIL_P$	5.427	
	H_0: $LnBOIL_P$ does not Granger cause $LnFO_P$	4.437	
$LnBOIL_P$ & $LnFW_P$	H_0: $LnFW_P$ does not Granger cause $LnBOIL_P$	5.186	
	H_0: $LnBOIL_P$ does not Granger cause $LnFW_P$	0.626	
$LnBOIL_P$ & $LnFM_P$	H_0: $LnFM_P$ does not Granger cause $LnBOIL_P$	**16.060***	$LnFM_P \rightarrow LnBOIL_P$
	H_0: $LnBOIL_P$ does not Granger cause $LnFM_P$	0.383	
$LnBOIL_P$ & $LnFB_P$	H_0: $LnFB_P$ does not Granger cause $LnBOIL_P$	2.097	
	H_0: $LnBOIL_P$ does not Granger cause $LnFB_P$	0.922	
$LnBOIL_P$ & $LnFR_P$	H_0: $LnFR_P$ does not Granger cause $LnBOIL_P$	3.249	
	H_0: $LnBOIL_P$ does not Granger cause $LnFR_P$	0.346	
$LnBOIL_P$ & $LnFSM_P$	H_0: $LnFSM_P$ does not Granger cause $LnBOIL_P$	**11.905***	$LnFSM_P \rightarrow LnBOIL_P$
	H_0: $LnBOIL_P$ does not Granger cause $LnFSM_P$	3.535	

Note: * denotes values larger than 5% significance level.

Table 10 Results Granger causality tests in levels, 1991-2001.

Period 1991M1-2001M12	Hypothesis	Test statistic (χ^2)	Granger causality
$LnBOIL_P$ & $LnFO_P$	H_0: $LnFO_P$ does not Granger cause $LnBOIL_P$	0.029	
	H_0: $LnBOIL_P$ does not Granger cause $LnFO_P$	0.107	
$LnBOIL_P$ & $LnFW_P$	H_0: $LnFW_P$ does not Granger cause $LnBOIL_P$	0.403	
	H_0: $LnBOIL_P$ does not Granger cause $LnFW_P$	0.014	
$LnBOIL_P$ & $LnFM_P$	H_0: $LnFM_P$ does not Granger cause $LnBOIL_P$	0.221	
	H_0: $LnBOIL_P$ does not Granger cause $LnFM_P$	0.450	
$LnBOIL_P$ & $LnFB_P$	H_0: $LnFB_P$ does not Granger cause $LnBOIL_P$	1.759	
	H_0: $LnBOIL_P$ does not Granger cause $LnFB_P$	0.074	
$LnBOIL_P$ & $LnFR_P$	H_0: $LnFR_P$ does not Granger cause $LnBOIL_P$	0.048	
	H_0: $LnBOIL_P$ does not Granger cause $LnFR_P$	1.714	
$LnBOIL_P$ & $LnFSM_P$	H_0: $LnFSM_P$ does not Granger cause $LnBOIL_P$	1.136	
	H_0: $LnBOIL_P$ does not Granger cause $LnFSM_P$	2.133	

Note: * denotes values larger than 5% significance level.

Table 11 Results Granger causality tests in levels, 2002-2013.

Period 2002M1-2013M12	Hypothesis	Test statistic (χ^2)	Granger causality
$LnBOIL_P$ & $LnFO_P$	H_0: $LnFO_P$ does not Granger cause $LnBOIL_P$	2.461	
	H_0: $LnBOIL_P$ does not Granger cause $LnFO_P$	**4.756***	$LnBOIL_P \rightarrow LnFO_P$
$LnBOIL_P$ & $LnFW_P$	H_0: $LnFW_P$ does not Granger cause $LnBOIL_P$	2.203	
	H_0: $LnBOIL_P$ does not Granger cause $LnFW_P$	2.274	
$LnBOIL_P$ & $LnFM_P$	H_0: $LnFM_P$ does not Granger cause $LnBOIL_P$	**11.633***	$LnFM_P \rightarrow LnBOIL_P$
	H_0: $LnBOIL_P$ does not Granger cause $LnFM_P$	0.826	
$LnBOIL_P$ & $LnFB_P$	H_0: $LnFB_P$ does not Granger cause $LnBOIL_P$	2.784	
	H_0: $LnBOIL_P$ does not Granger cause $LnFB_P$	0.424	
$LnBOIL_P$ & $LnFR_P$	H_0: $LnFR_P$ does not Granger cause $LnBOIL_P$	1.606	
	H_0: $LnBOIL_P$ does not Granger cause $LnFR_P$	0.399	
$LnBOIL_P$ & $LnFSM_P$	H_0: $LnFSM_P$ does not Granger cause $LnBOIL_P$	**8.940***	$LnFSM_P \rightarrow LnBOIL_P$
	H_0: $LnBOIL_P$ does not Granger cause $LnFSM_P$	2.024	

Note: * denotes values larger than 5% significance level.

5.3.2 Granger causality in price volatility

Price volatility is approximated by taking the quadratic values of the residuals (e2) obtained from the bi-variate VARs presented in previous subsection. A similar pattern occurs as with the tests for Granger causality in prices themselves, in this case a relationship running from the price volatility for animal feed to the price volatility for crude oil.

For the whole sample (Table 12) the price volatility of rye has a short-term relationship with crude oil. In the first sub period (Table 13) no Granger causality was detected. In the second sub period (Table 14) there is a Granger caused price volatility linkage running from maize and rye to crude oil.

Having the results at hand the following chapters will focus on discussing the outcomes, concluding the study and recommendations for future research.

Table 12 Results Granger causality tests in price volatilities, 1991-2013.

Period 1991M1-2013M12	Hypothesis	Test statistic (χ^2)	Granger causality
$e2_BOIL_P$ & $e2_FO_P$	H_0: $e2_FO_P$ does not Granger cause $e2_BOIL_P$	0.080	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FO_P$	2.307	
$e2_BOIL_P$ & $e2_FW_P$	H_0: $e2_FW_P$ does not Granger cause $e2_BOIL_P$	1.337	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FW_P$	0.456	
$e2_BOIL_P$ & $e2_FM_P$	H_0: $e2_FM_P$ does not Granger cause $e2_BOIL_P$	0.388	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FM_P$	0.095	
$e2_BOIL_P$ & $e2_FB_P$	H_0: $e2_FB_P$ does not Granger cause $e2_BOIL_P$	0.220	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FB_P$	1.067	
$e2_BOIL_P$ & $e2_FR_P$	H_0: $e2_FR_P$ does not Granger cause $e2_BOIL_P$	**6.883***	$e2_FR_P \rightarrow e2_BOIL_P$
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FR_P$	0.590	
$e2_BOIL_P$ & $e2_FSM_P$	H_0: $e2_FSM_P$ does not Granger cause $e2_BOIL_P$	0.370	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FSM_P$	0.001	

Note: * denotes values larger than 5% significance level.

Table 13 Results Granger causality tests in price volatilities, 1991-2001.

Period 1991M1-2001M12	Hypothesis	Test statistic (χ^2)	Granger causality
$e2_BOIL_P$ & $e2_FO_P$	H_0: $e2_FO_P$ does not Granger cause $e2_BOIL_P$	0.313	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FO_P$	0.343	
$e2_BOIL_P$ & $e2_FW_P$	H_0: $e2_FW_P$ does not Granger cause $e2_BOIL_P$	0.365	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FW_P$	0.244	
$e2_BOIL_P$ & $e2_FM_P$	H_0: $e2_FM_P$ does not Granger cause $e2_BOIL_P$	0.248	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FM_P$	0.186	
$e2_BOIL_P$ & $e2_FB_P$	H_0: $e2_FB_P$ does not Granger cause $e2_BOIL_P$	0.050	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FB_P$	0.380	
$e2_BOIL_P$ & $e2_FR_P$	H_0: $e2_FR_P$ does not Granger cause $e2_BOIL_P$	0.019	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FR_P$	0.338	
$e2_BOIL_P$ & $e2_FSM_P$	H_0: $e2_FSM_P$ does not Granger cause $e2_BOIL_P$	0.922	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FSM_P$	0.148	

Note: * denotes values larger than 5% significance level.

Table 14 Results Granger causality tests in price volatilities, 2002-2013.

Period 2002M1-2013M12	Hypothesis	Test statistic (χ^2)	Granger causality
$e2_BOIL_P$ & $e2_FO_P$	H_0: $e2_FO_P$ does not Granger cause $e2_BOIL_P$	0.929	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FO_P$	3.535	
$e2_BOIL_P$ & $e2_FW_P$	H_0: $e2_FW_P$ does not Granger cause $e2_BOIL_P$	4.335	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FW_P$	0.297	
$e2_BOIL_P$ & $e2_FM_P$	H_0: $e2_FM_P$ does not Granger cause $e2_BOIL_P$	**9.696***	$e2_FM_P \rightarrow e2_BOIL_P$
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FM_P$	0.601	
$e2_BOIL_P$ & $e2_FB_P$	H_0: $e2_FB_P$ does not Granger cause $e2_BOIL_P$	0.139	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FB_P$	0.515	
$e2_BOIL_P$ & $e2_FR_P$	H_0: $e2_FR_P$ does not Granger cause $e2_BOIL_P$	**8.765***	$e2_FR_P \rightarrow e2_BOIL_P$
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FR_P$	1.277	
$e2_BOIL_P$ & $e2_FSM_P$	H_0: $e2_FSM_P$ does not Granger cause $e2_BOIL_P$	1.634	
	H_0: $e2_BOIL_P$ does not Granger cause $e2_FSM_P$	0.324	

Note: * denotes values larger than 5% significance level.

6 Discussion

The aim of this study was to find out whether or not there are price and price volatility linkages between crude oil markets and European animal feed markets. Where the Chapters 2 and 3 laid out the literature available on potential linkages between these markets and providing an overview of the data used, in Chapters 4 and 5 the methodology of the tests was outlined and the results obtained from these tests were presented. In this chapter the data, methods and results will be critically assessed. Section 6.1 will discuss on the data, Section 6.2 the method and Section 6.3 the results.

6.1 Data

The data used for this study was sourced from different institutions (EU, World Bank and EIA) introducing potential differences in underlying assumptions of data collecting and processing. Not only was the data collected from different institutions, it was also sourced in different metrics (e.g. $/barrel, €/tonne). To overcome any data inconsistency, all price data was converted into the same currency (€), using the Euro\Dollar exchange rate. By converting the price data, it could be that additional information was added to the data set. However, because the point of interest is potential linkages between crude oil and animal feed, we look at a more abstract level and exact prices are less relevant.

Using monthly price data, relatively low frequency data was employed for this study. Although using monthly data to test for linkages between commodity markets is not uncommon, for example see Zhang et al. (2010) who investigate the impact of biofuels on global agricultural commodity prices or Gardebroek et al. (2013) for a study on volatility linkages between corn, wheat and soybean markets in the U.S.

It could be that using low frequency data, compared to daily or weekly commodity price data, higher prices volatility hides behind the averaging effect of using monthly data (O'Conner 2011). Therefore the actual volatility linkages found in this study can be understated and one should be cautious whilst interpreting the results.

6.2 Methodology

From the literature it is assumed that crude oil prices have an influence on the price paid for European animal feed commodities. Either through a direct channel in which crude oil is used as an input in growing, transportation and processing these crops or a more common channel of fundamental market factors through which both the price for crude oil as well as animal feed are influenced. Given the data available and practical limitations of the study, the choice was made to directly test the relationship between crude oil and selected feed commodities. However, given the recent increase in biofuel production for which commodities are sourced, which can also be used as animal feed, it could be useful to extent the model with an intermediate step introducing the prices for biofuels as in Natanelov et al. (2013). They found that U.S. corn markets became more prone to price volatility due to biofuel production, however not through a direct link, but a by-pass using crude oil markets.

Employing only a bi-variate model for testing short and long-term dynamics might be too narrowly defined for investigating the research objectives, since animal feed is often a combination of different feed commodities processed to form a single compound feed. Testing for price and volatility linkages in a multivariate setting, might be a better representation of reality using all raw materials at once.

6.3 Results

The results concerning the long-term dynamics or cointegration tests between crude oil and European animal feed prices did not show any surprising results. No long-term price relationship between the commodities under investigation was found using Two Step Engle-Granger and Johansen's cointegration tests. This result supports several studies, in that there is no long-term relationship between the prices of crude oil and prices of agricultural commodities that can be used for producing animal feed (Esmaeili and Shokoohi 2011; Reboredo 2012a).

Testing for short-term dynamics using Granger causality tests yielded counterintuitive results, that there is a casual link running from selected feed commodities to crude oil. This link feels counterintuitive, because one would expect given the importance of crude oil prices for the global economy, and the linkages found between agriculture and crude oil, any link existing between the two markets would be guided by the market for crude oil as supported by the literature. For example, Nazlioglu (2011) found Granger casual links running from crude oil to corn and soy beans. However, finding Granger causality running from agricultural commodities to crude oil prices is not a new phenomenon. Zhang et al. (2010) found sugar prices Granger cause crude oil prices and several other selected food commodities. Another study conducted by McPhail (2011), showed that ethanol prices (a proxy for corn prices) Granger cause crude oil prices, using monthly U.S. price data. Looking into detail, one finds a surprising difference between the two sub periods, namely that all dynamics took place in the period 2002M1-2013M12, indicating a change in price regime compared to the period 1991M1-2001M12.

The results might indicate that the markets for crude oil and animal feed in Europe are separated by certain price barriers preventing smooth price transmission from oil to feed commodities, even creating the results in which the prices for animal feed Granger cause the prices for crude oil. An explanation could be that price signals on both markets are not fully transmitted due to the EU's CAP, which can create a price barrier for certain commodities. Another explanation for the observed short-term price behaviour could be that European animal feed is produced using locally sourced raw materials that do not follow global economic trends dictated by the market for crude oil.

7 Conclusion and Future Research

The aim of this research was to discover a new part of price behaviour within agriculture: finding linkages between crude oil prices and European animal feed prices.

Literature study offered a first overview of what are the important channels through which the price of crude oil and animal feed are linked, helping us to understand the theoretical framework and putting the topic in a broader perspective. The main channels linking both markets are: direct oil/feed linkages, in which crude oil is used as input for the production of animal feed commodities and common oil/feed linkages (e.g. devaluation of the U.S. dollar) affecting both markets.

A flexible approach was used to test for long and short-term dynamics between the price series data. For testing long-term dynamics Two-step Engle-Granger and Johansen cointegration tests were employed. Exploring short-term dynamics Granger causality tests in price levels and price volatility provided the method for analysing the price data.

By checking the data for stationarity using unit root tests and determining the order of integration for the models, it was found that all prices are integrated of order one. The results show that there does not exist a significant long-term relationship between the prices for crude oil and the prices European animal feed. However, analysing for short-term dynamics one does find linkages between crude oil and European animal feed prices. The prices of maize and soy meal tend to Granger cause crude oil prices for the period 1991M1-2013M12 in levels. Similar behaviour was observed for maize and soy meal in the period 2002M1-2013M12. One exception in the results is the relation between crude oil and oats, where crude oil does Granger cause the prices of oats in the second sub period. Regarding volatility linkages, depicted by the test for Granger causality in quadratic values of the residuals of the VARs in price differences, only the volatility in the price of rye Granger causes crude oil during the period 1991M1-2013M12. Short-term price volatility linkages were also found running from maize and rye to crude oil in the period 2002M1-2013M12.

The overall results do indicate a change in price regime, between the crude oil market and European animal feed market since no long- nor short-term linkage was found during the period 1991M1-2001M12 compared to the more interlinked period starting in 2002M1 and ending in 2013M12.

This study did find a relation between crude oil and European animal feed markets for several cases. However, since this topic is relatively new, it thus offers ample opportunity for future research into the effects and interdependencies between the respective markets. For example, using a more extensive model including other variables such as, inflation rate, exogenous shocks, etc. the interplay between direct and common oil/feed links and its influence on both markets can be studied, potentially pointing to the causes, why price between crude oil and European animal feed are more interlinked since the beginning of 2002. Another extension could be to broaden the scope of the research, for example, do the price relations found for the European animal feed market also hold for other countries? Not only can this research be extended through a change in location, given price volatility linkages found in this study, a promising path of future research could also be to investigate the persistence of price volatility throughout the livestock value chain, expanding our knowledge on the topic of price behaviour in agricultural commodity markets.

References

Abbott, P. C., Hurt, C., Tyner, W.E. 2009. What's driving food prices? In *Issue Report*. Oak Brook, IL: Farm Foundation.

Baffes, J. 2007. Oil Spills on Other Commodities. In *Policy research working paper #4333*. Washington, D.C.: World Bank.

———. 2011. The long-term implications of the 2007–08 commodity-price boom. *Development in Practice* 21 (4-5): 517-525. http://dx.doi.org/10.1080/09614524.2011.562488.

Baffes, J., and A. Dennis. 2013. Long-Term Drivers of Food Prices. In *Policy research working paper #6455*. Washington, D.C.: World Bank.

Berazneva, J., and D. R. Lee. 2013. Explaining the African food riots of 2007–2008: An empirical analysis. *Food Policy* 39 (0): 28-39. http://dx.doi.org/http://dx.doi.org/10.1016/j.foodpol.2012.12.007.

Chow, K. W. 1978. Storage Problems in Feedstuffs. Paper read at FAO/UNDP Training Course in Fish Feed Technology, at Seattle.

Cooke, B., and M. Robles. 2009. Recent Food Prices Movements: A Time Series Analysis. In *IFPRI Discussion Paper #00942*. Washington, D.C.: International Food Policy Research Institute.

Cooper, J. C. B. 2003. Price elasticity of demand for crude oil: estimates for 23 countries. *OPEC Review* 27 (1): 1-8. http://dx.doi.org/10.1111/1468-0076.00121.

Davidson, R., and J. G. MacKinnon. 1993. *Estimation and Inference in Econometrics*. New York: Oxford University Press.

Dickey, D. A., and W. A. Fuller. 1979. Distribution of the Estimators for Autoregressive Time Series With a Unit Root. *Journal of the American Statistical Association* 74 (366): 427-431. http://dx.doi.org/10.2307/2286348.

Du, X., C. L. Yu, and D. J. Hayes. 2011. Speculation and volatility spillover in the crude oil and agricultural commodity markets: A Bayesian analysis. *Energy Economics* 33 (3): 497-503. http://dx.doi.org/http://dx.doi.org/10.1016/j.eneco.2010.12.015.

EC. 2011. The EU cereals regime. Brussel: European Commission, Directorate-General for Agriculture and Rural Development.

———. *Cereals, oilseeds and protein crops, rice*. European Commission, Agriculture and Rural Development 2014a [cited 19-02-2014. Available from http://ec.europa.eu/agriculture/cereals/.

———. 2014b. Commodity price dashboard 1997-2013. edited by Agriculture and Rural development European Commission. Brussels.

Edwards, R., S. Szekeres, F. Neuwahl, and V. Mahieu. 2008. Biofuels in the European Context: Facts and Uncertainties. edited by Giovanni De Santi. Petten: European Commission Joint Research Centre.

EIA. 2014a. Cushing, OK Crude Oil Future Contract 1 1991-2013. edited by Energy Information Administration. Washington, D.C.

———. *FAQ: How much does it cost to produce crude oil and natural gas?* 2014b [cited 14-02-2014. Available from http://www.eia.gov/tools/faqs/faq.cfm?id=367&t=6.

Energy Intelligence. 2004. *Understanding the Oil and Gas Industries*. Edited by Energy Intelligence. New York.

Engle, R. F., and C. W. J. Granger. 1987. Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica* 55 (2): 251-276. http://dx.doi.org/10.2307/1913236.

Esmaeili, A., and Z. Shokoohi. 2011. Assessing the effect of oil price on world food prices: Application of principal component analysis. *Energy Policy* 39 (2): 1022-1025. http://dx.doi.org/http://dx.doi.org/10.1016/j.enpol.2010.11.004.

EUFETEC. 2013. Vision & SRIA Document 2030 Feed for Food Producing Animals. Brussel: European Feed Technology Center.

Eurostat. 2014. Animal output - basic and producer prices. Eurostat.

FAO. 2013. FAO Food Price Index. Rome.

FEFAC. 2012. Feed & Food: Statitical Yearbook 2012. Brussel: The European Feed Manufacturers' Federation.

———. 2013. The Feed Chain in Action. Brussel: The European Feed Manufacturers' Federation.

Gardebroek, C., M. A. Hernandez, and M. Robles. 2013. Market interdependence and volatility transmission among major crops. Agricultural and Applied Economics Association.

Gilbert, C. L. 2010. How to Understand High Food Prices. *Journal of Agricultural Economics* 61 (2): 398-425. http://dx.doi.org/10.1111/j.1477-9552.2010.00248.x.

Granger, C. W. J., and P. Newbold. 1974. Spurious regressions in econometrics. *Journal of Econometrics* 2 (2): 111-120. http://dx.doi.org/http://dx.doi.org/10.1016/0304-4076(74)90034-7.
Gutierrez, L. 2013. Speculative bubbles in agricultural commodity markets. *European Review of Agricultural Economics* 40 (2): 217-238. http://dx.doi.org/10.1093/erae/jbs017.
Headey, D., and S. Fan. 2008. Anatomy of a crisis: the causes and consequences of surging food prices. *Agricultural Economics* 39: 375-391. http://dx.doi.org/10.1111/j.1574-0862.2008.00345.x.
Irwin, S. H., and D. R. Sanders. 2011. Index Funds, Financialization, and Commodity Futures Markets. *Applied Economic Perspectives and Policy* 33 (1): 1-31. http://dx.doi.org/10.1093/aepp/ppq032.
Irwin, S. H., D. R. Sanders, and R. P. Merrin. 2009. Devil or angel? The role of speculation in the recent commodity price boom (and bust). *Journal of Agricultural and Applied Economics* 41 (2): 377-391.
Johansen, S. 1991. Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. *Econometrica* 59 (6): 1551-1580. http://dx.doi.org/10.2307/2938278.
Kesicki, F. 2010. The third oil price surge – What's different this time? *Energy Policy* 38 (3): 1596-1606. http://dx.doi.org/http://dx.doi.org/10.1016/j.enpol.2009.11.044.
Kilian, L., and B. Hicks. 2013. Did Unexpectedly Strong Economic Growth Cause the Oil Price Shock of 2003–2008? *Journal of Forecasting* 32 (5): 385-394. http://dx.doi.org/10.1002/for.2243.
Krichene, N. 2008. Crude Oil Prices: Trends and Forecast. In *IMF Working Papers*: International Monetary Fund.
Kumar, M., and N. Verma. *Iran, India meet to discuss oil exports, payments*. Reuters 2013 [cited 15-02-2014. Available from http://in.reuters.com/article/2013/12/10/india-iran-oil-idINDEE9B906S20131210.
Lizardo, R. A., and A. V. Mollick. 2010. Oil price fluctuations and U.S. dollar exchange rates. *Energy Economics* 32 (2): 399-408. http://dx.doi.org/http://dx.doi.org/10.1016/j.eneco.2009.10.005.
MacKinnon, J. G. 1996. Numerical distribution functions for unit root and cointegration tests. *Journal of Applied Econometrics* 11 (6): 601-618. http://dx.doi.org/10.1002/(sici)1099-1255(199611)11:6<601::aid-jae417>3.0.co;2-t.
Mackinnon, J. G., A. A. Haug, and L. Michelis. 1999. Numerical Distribution Functions of Likelihood Ratio Tests for Cointegration. *Journal of Applied Econometrics* 14 (5): 563-577. http://dx.doi.org/10.2307/223206.
McPhail, L. L. 2011. Assessing the impact of US ethanol on fossil fuel markets: A structural VAR approach. *Energy Economics* 33 (6): 1177-1185. http://dx.doi.org/http://dx.doi.org/10.1016/j.eneco.2011.04.012.
Mileva, E., and N. Siegfried. 2012. Oil market structure, network effects and the choice of currency for oil invoicing. *Energy Policy* 44 (0): 385-394. http://dx.doi.org/http://dx.doi.org/10.1016/j.enpol.2012.02.002.
Mitchell, D. O. 2008. A note on rising food prices. In *Policy research working paper #4682*. Washington, D.C.: World Bank.
Myers, R. J. 1994. Time Series Econometrics and Commodity Price Analysis: A Review. *Review of Marketing and Agricultural Economics* 62 (2): 167-181.
Natanelov, V., A. M. McKenzie, and G. Van Huylenbroeck. 2013. Crude oil–corn–ethanol – nexus: A contextual approach. *Energy Policy* 63 (0): 504-513. http://dx.doi.org/http://dx.doi.org/10.1016/j.enpol.2013.08.026.
Nazlioglu, S. 2011. World oil and agricultural commodity prices: Evidence from nonlinear causality. *Energy Policy* 39 (5): 2935-2943. http://dx.doi.org/http://dx.doi.org/10.1016/j.enpol.2011.03.001.
O'Conner, D. a. K., Michael. 2011. "Empirical Issues Relating to Dairy Commodity Price Volatility." In *Methods to Analyse Agricultural Commodity Price Volatility*, edited by I. Piot-Lepetit, M'Barek, M. New York: Springer Science+Business Media.
OECD. 2008. Rising Food Prices: Causes and Consequences. Paris: OECD.
OPEC. 2012. OPEC Annual Statistical Bulletin. Vienna: OPEC.
Reboredo, J. C. 2012a. Do food and oil prices co-move? *Energy Policy* 49 (0): 456-467. http://dx.doi.org/http://dx.doi.org/10.1016/j.enpol.2012.06.035.
———. 2012b. Modelling oil price and exchange rate co-movements. *Journal of Policy Modeling* 34 (3): 419-440. http://dx.doi.org/http://dx.doi.org/10.1016/j.jpolmod.2011.10.005.
Rezitis, A. N., and K. S. Stavropoulos. 2010. Modeling beef supply response and price volatility under CAP reforms: The case of Greece. *Food Policy* 35 (2): 163-174. http://dx.doi.org/http://dx.doi.org/10.1016/j.foodpol.2009.10.005.

Rezitis, A. N., and K. S. Stavropoulos. 2011. Price transmission and volatility in the greek broiler sector: A threshold cointegration analysis. *Journal of Agricultural and Food Industrial Organization* 9 (1).

Said, S. E., and D. A. Dickey. 1984. Testing for Unit Roots in Autoregressive-Moving Average Models of Unknown Order. *Biometrika* 71 (3): 599-607. http://dx.doi.org/10.2307/2336570.

Sanders, D. R., and S. H. Irwin. 2011. New Evidence on the Impact of Index Funds in U.S. Grain Futures Markets. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 59 (4): 519-532. http://dx.doi.org/10.1111/j.1744-7976.2011.01226.x.

Schnepf, R. 2005. Price determination in Agricultural Commodity Markets: A Primer. In *CRS report for Congress*. Washington, D.C.: Congressional Research Service.

Serra, T. 2011. Food scare crises and price volatility: The case of the BSE in Spain. *Food Policy* 36 (2): 179-185. http://dx.doi.org/http://dx.doi.org/10.1016/j.foodpol.2010.11.006.

Taheripour, F., T. W. Hertel, W. E. Tyner, J. F. Beckman, and D. K. Birur. 2010. Biofuels and their by-products: Global economic and environmental implications. *Biomass and Bioenergy* 34 (3): 278-289. http://dx.doi.org/http://dx.doi.org/10.1016/j.biombioe.2009.10.017.

Tyner, W. E., and F. Taheripour. 2008a. Biofuels, Policy Options, and Their Implications: Analyses Using Partial and General Equilibrium Approaches. *Journal of Agricultural and Food Industrial Organization* 6 (2). http://dx.doi.org/10.2202/1542-0485.1234.

———. 2008b. Policy Options for Integrated Energy and Agricultural Markets. *Review of Agricultural Economics* 30 (3): 387-396. http://dx.doi.org/10.2307/30225881.

Uri, N. D. 1996. Changing crude oil price effects on US agricultural employment. *Energy Economics* 18 (3): 185-202. http://dx.doi.org/http://dx.doi.org/10.1016/0140-9883(96)00018-7.

World Bank. 2014. Brent Oil prices 1991-2013. edited by World Bank.

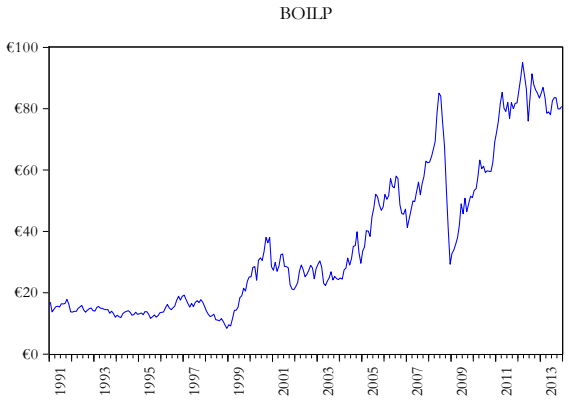
Wright, B. D. 2011. The Economics of Grain Price Volatility. *Applied Economic Perspectives and Policy* 33 (1): 32-58. http://dx.doi.org/10.1093/aepp/ppq033.

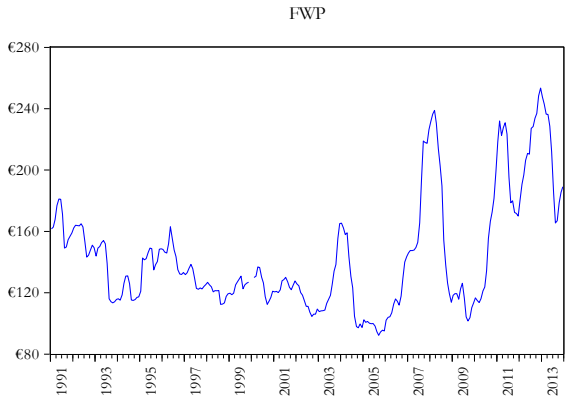
Zhang, Z., L. Lohr, C. Escalante, and M. Wetzstein. 2010. Food versus fuel: What do prices tell us? *Energy Policy* 38 (1): 445-451. http://dx.doi.org/http://dx.doi.org/10.1016/j.enpol.2009.09.034.

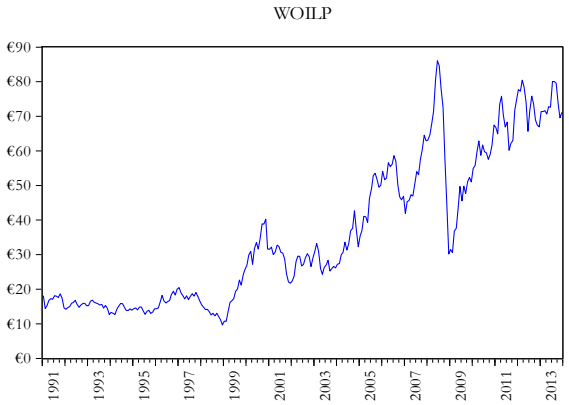
Appendix A

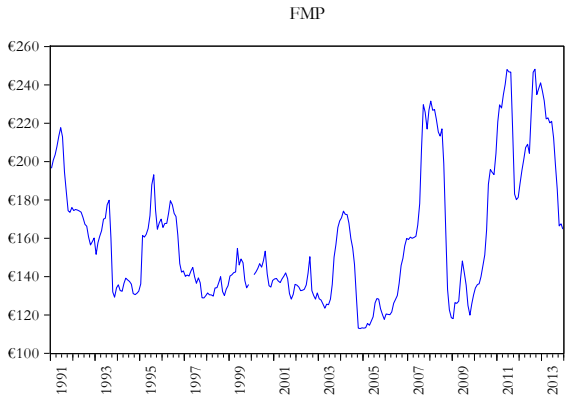
Graphical representation of all price series in levels and volatility for the period January 1991 to December 2013.

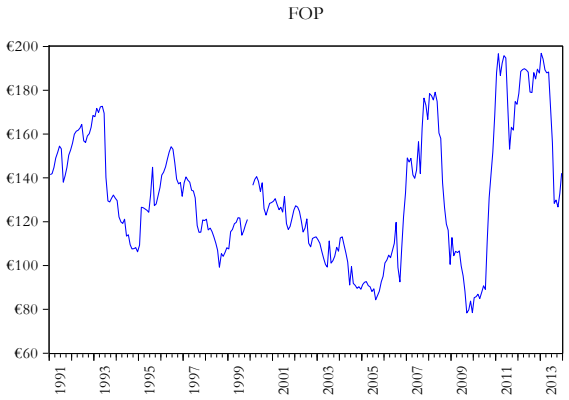
Monthly prices all commodities January 1991 to December 2013

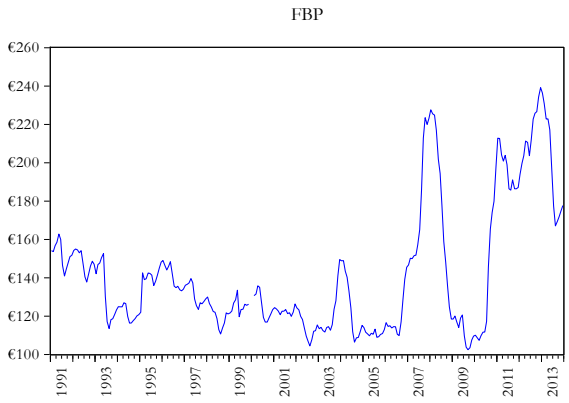


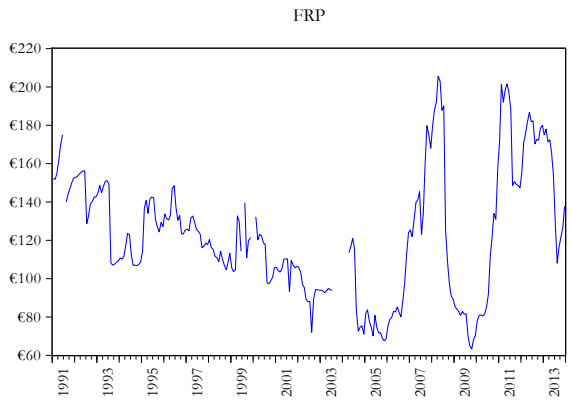


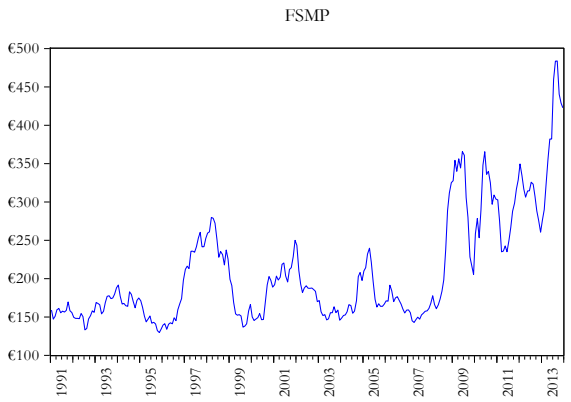




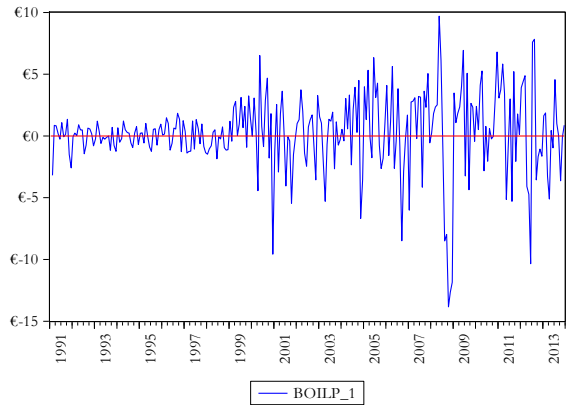


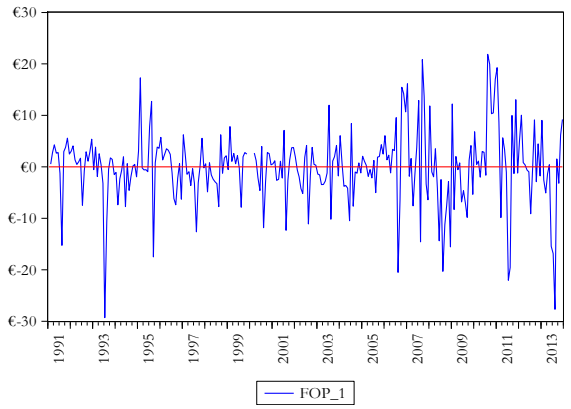


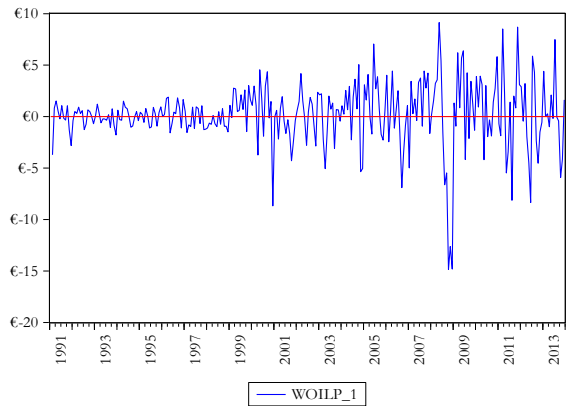


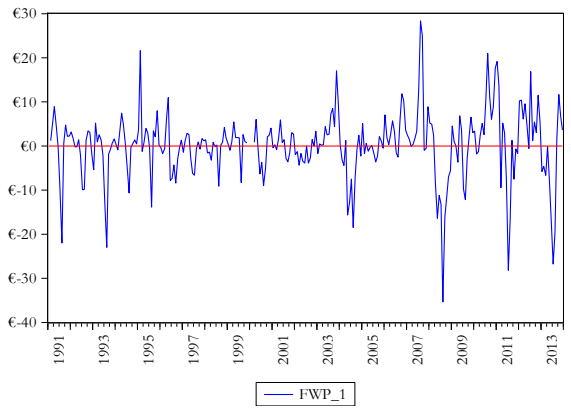


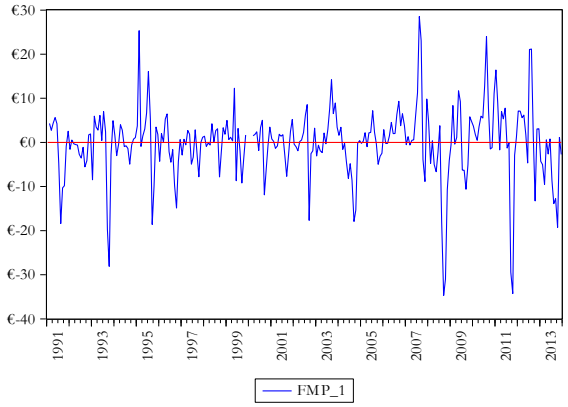
Monthly Price Volatility all commodities January 1991 to December 2013

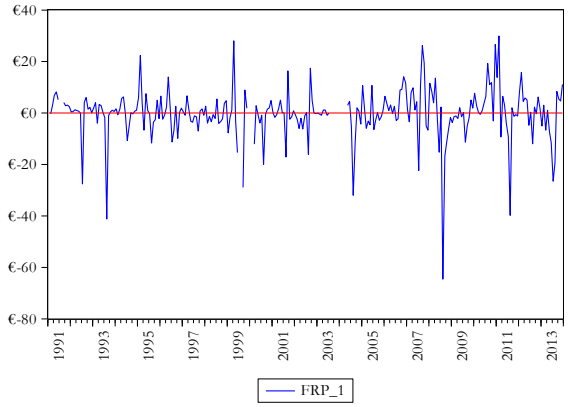


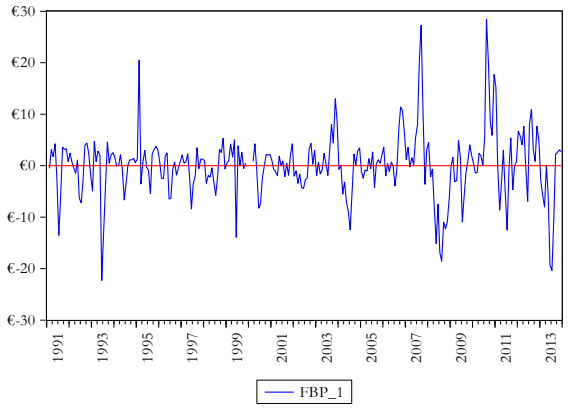


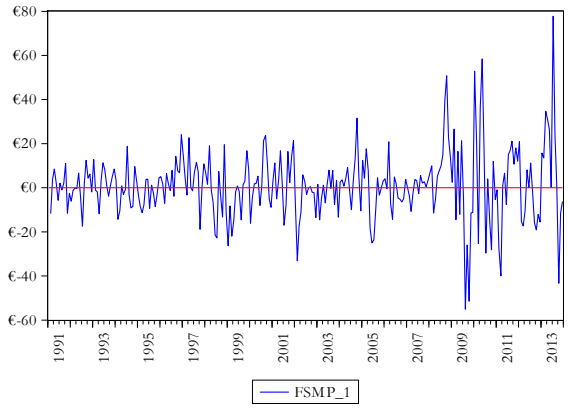





€30
€20
€10
€0
€-10
€-20
€-30
€-40
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
FMP_1


€40
€20
€0
€-20
€-40
€-60
€-80
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
FRP_1


€30
€20
€10
€0
€-10
€-20
€-30
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
FBP_1


€80
€60
€40
€20
€0
€-20
€-40
€-60
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
FSMP_1