NORGES HANDELSHØYSKOLE

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Price comovement in energy and commodity markets

Bjarne Inge Johansen

Supervisor: Rögnvaldur Hannesson

Master thesis within the major profile of Energy, Natural Resources and the Environment

NORGES HANDELSHØYSKOLE

Abstract

This master thesis examines geographical market integration in energy markets, price comovement between oil, natural gas and coal, as well as price comovement between energy and non-energy commodities (agricultural products, industrial metals and precious metals). A relatively comprehensive review of the literature is made, and a cointegration analysis between crude oil and various non-energy commodities is also carried out. The findings indicate that oil is quite strongly integrated into one global market, although recent developments imply that this may change. Coal markets are not as strongly integrated as oil, but the presence of a single global coal market is still likely. Natural gas markets are probably divided in two, perhaps three, global markets. Some relatively strong regional integration between energy carriers exists, but there is no integrated common market. Several long-term price relationships between energy and non-energy commodities also seem to be present, but it is very difficult to determine which causal factors are responsible.

Preface

This thesis is the final work of my Master of Science with the major profile of energy, natural resources and the environment at the Norwegian School of Economics (NHH).

Originally, I considered writing a thesis within market integration in fisheries markets, more specifically I wanted to research the impact of new and relatively cheap species such as pangasius, tilapia and nile perch on the European white fish market. I discussed this with my supervisor Rögnvaldur Hannesson and even obtained data from the Norwegian Seafood Export Council. However, during the autumn semester of 2010 I was inspired by a course held by professor Ole Gjølberg at NHH, among other things, to instead write my thesis within energy commodity markets. As professor Hannesson in addition to fisheries economics also teaches resource and petroleum economics, my new topic also fit nicely within his area of expertise and thus I changed topic.

Writing this thesis has been challenging, from the early process of finding data and identifying the relevant literature to the later stages of discussing the findings and causal relationships. It has also been rewarding and interesting and I feel I have learned a lot about energy and commodity markets.

I would like to thank my supervisor professor Rögnvaldur Hannesson for his comments and valuable help during the writing of my thesis. It was great to have a supervisor who always responded quickly and with insight to all my questions and to the various drafts I handed in. I am also grateful to my parents, Venke A. Johansen and Rolf Thorsen, as well as my brother Magne Johansen, for their support. Finally, I would like to thank all my friends at NHH for the great years I have spent there.

All errors or inaccuracies that remain are fully my own.

Bjarne Inge Johansen
Bergen, August 2011

Abbreviations

ADF test: Augmented Dickey Fuller test

AIC: Akaike information criterion

EIA: Energy Information Administration of the USA

EJ: Exajoule, 10^{18} joule

EMH: Efficient Market Hypothesis

EPA: Environmental Protection Agency of the USA

FAO: Food and Agriculture Organization of the United Nations

IFA: International Fertilizer Industry Association

GJ: Gigajoule, 10^{9} joule

IEA: International Energy Agency

IMF: International Monetary Fund

LNG: Liquefied Natural Gas

MJ: Megajoule, 10^{6} joule

R/P ratio: Reserves-to-production ratio

REN21: Renewable Energy Policy Network for the 21st Century

WTI: West Texas Intermediate crude oil

Contents

1. Introduction

During the second half of the 2000's the world experienced dramatic developments in commodity markets. From January 2007 to the price peak during the summer of 2008, the nominal price of crude oil increased by 146 %, corn by 74 %, wheat by 77 % and iron ore by 66 %[1]. This commodity price boom was stronger than any experienced in the 20th century (World Bank 2009). In particular the high food prices were hotly debated, and the hunger, social unrest, riots and export bans that followed them was dubbed the "food crisis" by the media. After the boom of 2007/08, commodity prices plummeted before rebounding quite strongly in 2010 and 2011. These events have underlined the importance of energy, metals, mineral and food prices for the world economy and have sparked renewed interest in how these prices are related.

This paper seeks to analyze some aspects of commodity price comovement with a particular focus on energy. The aim is to examine how energy commodities interact with each other as well as other commodity types, and if possible determine some of the reasons behind the observed price behavior. I have chosen the following problem statements:

> How do the prices of international energy commodities comove geographically and across energy carriers? How do the prices of energy commodities comove with the prices of other commodities, specifically agricultural commodities[2], industrial metals/minerals and precious metals?

1.1 Definitions

An important aspect of determining how the prices of different commodities interact is based on establishing whether they comove closely enough to be considered part of the same market. There are several ways of empirically determining this, three common methods are

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[1] These numbers are from a price series for commodities collected from the historical commodity database at indexmundi.com. A detailed description of the characteristics of each price series and graphs showing the development over time is included in appendix A.

[2] If one wanted to be entirely precise, food *is* an energy commodity, as it supplies us humans with the energy we need to function. However, food is not directly substitutable with conventional energy in the economic sense, and will therefore be considered a non-energy commodity. Of course, traditional energy commodities are substitutable with biofuels and this will be considered as a part of the analysis.

based on (1) cross-price elasticities of demand, (2) product flows or (3) price-based definitions (Li 2007). In this paper I will apply the price-based definition, which is also the most commonly used in economics (Barret 2001). The idea of determining the extent of market integration based on price can be traced back to the writings of Antoine Augustin Cournot, who in 1838 wrote:

"It is evident that an article capable of transportation must flow from the market where its value is less to the market where its value is greater, until difference in value, from one market to the other, represents no more than the cost of transportation" (1971: p. 10, reprint and translation of 1838 French original).

Later, Alfred Marshall (1890) and George Stigler (1987) followed up with similar definitions. Stigler's version is commonly used and defines a market as *"the area within which the price of a commodity tends to uniformity, allowance being made for transportation costs."* (1987: p. 77, reprint of original published in 1966).

Two more expressions also need some further explanation. The terms *market integration* and *price comovement* are both frequently used in the literature and a clarification of how the two terms relate to each other is in its place. Market integration refers to prices being positively correlated with each other, presumably (but not necessarily) due to a high degree of substitution between the commodities or products in question[3]. This expression is used frequently when examining geographical or quality differences within the same type of commodity or product, but also sometimes in studies of how different commodities relate to each other. Price comovement on the other hand is a more neutral and wider term[4]. It refers to the tendency of commodity prices to move together (positively or negatively) and there is no (implicitly) stated reason as to why these comovements occur. A brief overview of the research tradition within commodity price comovement will be provided at the beginning of chapter 2.

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[3] There seems to be no general consensus in the literature about *how closely* the prices must be correlated for the markets to be classified as integrated. This may vary from article to article (Barret 2001). In practical application, the most used price-based method of determining market integration is based on cointegration. If the price series of two commodities (or one commodity in two different locations) are cointegrated, they are often classified as being integrated in the same market. Note that market integration may also be based on the other two definitions previously mentioned, cross-price elasticities of demand or product flows (Barret 2001).

[4] The term price comovement is also frequently used in articles that discusses or cites a seminal paper by Pindyck & Rotemberg (1990) named *"The Excess Co-movement of Commodity Prices"*, and one could perhaps say that the term stems from the tradition following that article.

In this paper I will use the terms market integration and price comovement somewhat freely. However, the term market integration will be used only when describing positively correlated price series. Note that I do not assume that the cause is necessarily substitution effects.

1.2 Limitations to the scope of the project

Due to the dominating role of fossil fuels in the market for energy commodities, as well as the important role played by regulation and grid infrastructure in electricity markets, the analysis of energy commodity markets in this project will be limited to oil, natural gas and coal markets. Markets for electricity, nuclear energy and renewable energy will not be considered. Bioethanol and biodiesel markets will be considered in relation to the impact they could have on the price link between agricultural products and energy markets, but will not be analyzed separately.

This paper will also be concerned with long-term rather than short-term price relations and this will be the main focus both when reviewing the relevant literature and in the empirical analysis. However, short-term price relations will sometimes be considered when they are relevant to the overall discussion.

1.3 Why is commodity price comovement important?

To some, the topic of commodity price comovement may appear overly theoretical and the relevance seem unclear. However, the presence (or absence) of price comovement in commodity markets does in fact have important implications for several groups, including policy makers, producers, consumers and investors.

Understanding the way commodity prices move together is central for policy makers in analyzing how and to what degree market conditions, regulation and policies affect prices. If commodity markets are integrated, they cannot be analyzed in isolation from each other as the impacts of events that seemingly affect one only market eventually will have an impact on the other markets as well. An important example from recent years can be found in relation to price comovement between energy and agricultural markets. High food prices and high volatility in staple food commodities has been a major international concern, especially after the food crisis of 2007 and 2008. A considerable portion of the world's population uses a large part of their budgets to buy food, and therefore they have little flexibility to cope with large price increases for staple food products or high price volatility[5]. Many economic policies have been aimed at reducing both volatility and overall price levels for poor consumers and this is certainly a desirable goal. However, if prices in agricultural and energy markets comove, this must be taken into account when determining policies. As an example, assume that crude oil markets and wheat markets are integrated. If a global carbon tax is implemented to prevent the negative externalities from the burning of fossil fuels (e.g. climate change, local pollution or issues concerning security of supply) then this is likely to, ceteris paribus, increase the price of wheat[6].

Another area where market integration is relevant is within competition and antitrust issues, as the extent of geographical market integration and integration across products is vital in determining the market size and the market power of individual actors. As an example, imagine hypothetically that the international markets for oil, natural gas and coal are integrated. One international market for fossil energy implies that e.g. a single coal company would have less market power than if coal markets were not integrated with other energy types and limited to a smaller geographical area. For the coal company, attempts at exploiting market power are likely to be unsuccessful even if it controls a substantial part of the national coal market. For competition authorities, the example above implies that they should treat oil, natural gas and coal markets as one. They may allow companies to grow larger through mergers and acquisitions than what would be sensible in a smaller market, but they should also be aware of a company's total market share in fossil fuels and not only focus on the market share in the production of one energy commodity when deciding on regulation.

Commodity price comovement is also of importance in risk management for commodity producers, large consumers and investors, as the relations between commodity prices are vital for the definition of risk measurement and management tools. If commodity prices

[5] The average person living below the global poverty line (here defined as $ 1 per day or less) normally uses from 56 % to 74 % of his or her total budget to buy food, depending on the country (Banjeree & Duflo 2007).

[6] Note that this is not a normative statement. I am not arguing that a global carbon tax is undesirable, I am only pointing out that policy makers should be aware of the full effects of policies affecting commodity markets when prices comove. All relevant tradeoffs should be taken into account, including the likely effects on food prices.

comove to a large extent, this affects the systematic risk of commodity markets. Additionally, if the prices of two commodities move together, one may be used to hedge risk in the other.

1.4 Structure of thesis

Chapter two will review the literature on commodity price comovement geographically, across energy carriers and between energy and non-energy commodities. It will also give a short overview of the early research within commodity price comovement and the seminal contributions to the field, as well as some of the fundamental characteristics of the relevant energy markets. In chapter three I will present the methods used in the econometric analysis, all of which will be within time series econometrics. In chapter four I will describe the motivation for data selection and present descriptive statistics, while chapter five will contain the econometric analysis. Chapter six will compare the findings of the analysis with the literature and discuss causal factors, while chapter seven concludes. Considerably more literature is available on geographical market integration than price comovement across energy commodities, and even less literature is available on the relations between energy and non-energy commodities. This results in the topic of geographic price comovement somewhat dominating the literature review in chapter two, while the relations between energy and non-energy commodities are given more space in the analysis and discussion parts.

2. Theory and literature overview

"Books serve to show a man that those original thoughts of his aren't very new at all" - Abraham Lincoln

Price comovement in commodity markets has been extensively researched in a wide range of contexts, for example within agricultural, mineral, energy and fish markets. This chapter will provide a brief overview of the literature and theory on commodity price comovement. To get a better overview of the issue I will first briefly introduce the early seminal contributions at the general level. Then, a review of the more recent research specifically concerned with energy markets will be presented and finally review of the price relationships between energy commodities and non-energy commodities. I will discuss the characteristics of the markets for different commodities and the fundamental relationships between them where it seems fitting throughout this chapter. A more thorough discussion of fundamental causes of price comovement will be presented in chapter six.

It is possible to roughly classify the research on commodity price comovement into two broad groups, one concerned mainly with *spatial* price comovement and the other concerned with price comovement *across commodities* (Baffes 2009). This paper is concerned with both issues, but more emphasis is put on how prices move together across commodities. Nevertheless, spatial price comovement is also an important aspect to consider as part of the analysis and knowledge about this topic enhances the understanding of the issues concerning price comovement across commodities. Since many early contributions to the theory on price comovement and market integration were concerned with the spatial element, this is a natural place to start.

2.1 Spatial price comovement

The research within spatial price comovement is concerned with how closely the prices of (reasonably) homogenous products follow each other in different geographical locations. Although the price-based definition of market integration can be traced back to the 19th century[7], empirical research on the topic did not really start until the 1950's (Wårell 2006).

[7] As previously mentioned, the ideas behind this definition can be traced at least back to Antoine Augustin Cournot's writings in 1838.

Many attempts to analyze spatial and intertemporal market integration were made, especially within agricultural economics. However, the early studies struggled with methodological issues (Barret 1996), and it was not until the second half of the 1980's that major methodological breakthroughs were made. One of these breakthroughs came with Ravallion (1986), who developed an error correction model with a central (urban) market that influences the price in several local markets. Another very important innovation was the cointegration approach to time series econometrics, where Engle & Granger (Granger 1986, Engle & Granger 1987) as well as Johansen (1988) were the main contributors. Today, studies on geographical market integration have been carried out in a multitude of economic markets and cointegration and error correction models are commonly used as part of the toolbox available to economists.

2.2 Price comovement across commodities

Although it is useful to conceptually distinguish between spatial market integration and price comovement across commodities or products, the methodological approach to the two issues has to a very large degree sprung from the same ideas and research. Once a framework and methodology for examining geographical price comovement was developed, the next logical step was applying those same methods to investigate the relationships between different quality types of the same commodity or the relationships between different kinds of commodities. Thus, cointegration and error correction models have played a major role and much of the research on price comovement stems from geographical market integration research.

An influential paper within market integration across commodities was written by Clive Granger (1986), who wrote: *"if x_t and y_t are a pair of prices from a jointly efficient speculative market, they cannot be cointegrated. (…) if the two prices were cointegrated, one can be used to help forecast the other and this would contradict the efficient market assumption"* (p. 218). Granger's claim spurred research within comovement in commodities and exchange rate markets (MacDonald & Taylor 1988, Baillie & Bollerslev 1989, Hakkio & Rush 1989), but the idea that commodity comovement represents a contradiction to the efficient market hypothesis was later rejected on several grounds. Most importantly, price comovement can be a result of economic fundamentals rather than market inefficiencies (Agbeyebbe 1992, Baffes 1993, Dwyer & Wallace 1992, Baffes 2009). These fundamentals may be that commodities are substitutes, complements, input factors to each other or coproduced. The influence of macroeconomic factors, such as economic shocks or exchange rates could also play an important role and must be taken into account when attempting to establish causality.

A second seminal paper within commodity price comovement was published by Pindyck & Rotemberg (1990), where the two economists found very strong evidence of price comovement within a group of seven commodities that should be unrelated in terms of economic fundamentals (cross-price elasticities of demand and supply close to zero) and after controlling for macroeconomic conditions. This *"excess comovement of commodity prices"* (Pindyck & Rotemberg 1990) challenges the informational efficiency of commodity markets. Proposed explanations by Pindyck and Rotemberg were market psychology (herd behavior, bubbles) or liquidity constraints (where traders holding several assets are forced to sell because of a large price drop in one of them).

Later studies have both disputed and confirmed Pindyck & Rotemberg's original findings. Some have criticized the original study on the basis of the econometric methods used, e.g. Cashin, McDermott & Scott (1999) who after applying their own method for analyzing time series[8] found that almost all excess comovement in commodity prices disappears. Others, such as Lescaroux (2009), have criticized Pindyck & Rotemberg for not controlling sufficiently for macroeconomic factors. Others studies again, have confirmed the original findings of Pindyck & Rotemberg (e.g. Blankmeyer 2006 or Le Pen & Sévi 2010). Due to the difficult question of which factors to control for and how, the matter of excess price comovement in commodity markets still remains an issue that is not entirely settled.

2.3 Price comovement in energy markets

I now move from providing an overview of the general and early research on commodity price comovement to issues specifically concerned with energy markets. A multitude of

[8] Cashin, McDermott & Scott applies concordance analysis. It implies first using an algorithm (in this case the Bry-Boschan algorithm) to identify boom and slump periods in a price series and then using a test statistic to determine if two price series significantly comove. The method only takes price direction into account (slump or boom) and not the size of price movement and is thus, according to Cashin, McDermott & Scott, better suited in dealing with price spikes. The method has (to my knowledge) only been applied to commodity price series analysis by the authors in question. Lescaroux (2009) criticizes the method for only being able to identify simultaneous relationships, i.e. not lead or lag relationships.

literature on geographical market integration within energy markets is available, and a selected overview of some of those studies will be presented in section 2.3.1. The literature investigating price relationships between oil, coal and natural gas is more limited, however some studies do exist and a summary of these will be provided in section 2.3.2. Before considering the literature, some key characteristics of energy commodity markets will be presented.

The market for commercially traded energy commodities is largely dominated by fossil fuels. Oil is the largest commodity with around 33 % of the market, followed by coal with 30 % and natural gas with 24 %. Nuclear and renewable energy make up 5 % and 8 % respectively. The figures are illustrated in figure 2.1.

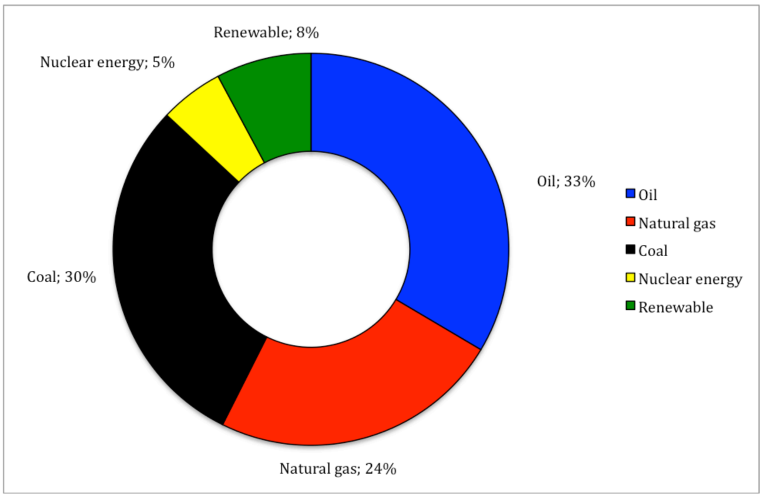

Figure 2.1: World consumption of primary energy in traded fuels. *Source: BP Statistical Review of World Energy 2011. Fossil fuels dominate the market for traded fuels with a total percentage of roughly 87 %. Total consumption in 2011 equaled ca 503 EJ.*

2.3.1 Geographical energy markets

This section will start with a discussion of practical reasons behind differing levels of integration in energy commodity markets, and then proceed to go through the characteristics and academic literature on each individual market.

2.3.1.1 Practical limits to market integration

As Morris Adelman (1984) famously put it, "*the world oil market, like the ocean, is one great pool"* (p. 5). World natural gas and coal markets however, unlike the ocean, are not one big pool. In more academic terms, it does not appear that coal and natural gas markets are as well integrated as oil markets. One of the main reasons for less integration in coal and natural gas markets are transaction costs, as natural gas and coal are more difficult and costly to transport and handle than crude oil. Oil has a high energy content per weight unit, with a calorific value of roughly 40 to 45 MJ/kg. Furthermore, crude oil is of course liquid and therefore easy to handle and transport using standardized ships and infrastructure. Coal on the other hand is more bulky; it cannot be "filled" into a tank and must be physically lifted into railways or dry bulk ships for transportation. In addition, its energy content per weight is about half that of oil with a calorific value of around 20 MJ/kg, which means that more coal must be provided to be able to extract the same amount of energy compared to oil. However, international bulk shipping has become very effective and even in terms of energy content, the cost of transporting coal from port to port is not that much higher than for crude oil tankers. Coal transport on land is done by mainly by rail[9] and is more expensive than by ship (see figure 2.2 for shipping and rail transport costs of coal).

Natural gas actually has a *higher* energy content per weight unit than crude oil, with calorific values ranging from 50 to 55 MJ/kg. However, looking at this number is misleading as natural gas has a substantially lower density than crude oil. This implies that much larger *volumes* must be transported relatively to oil to obtain the same amount of energy. One thousand cubic meters of natural gas has roughly the same energy content as a metric ton of oil, but a metric ton of oil only uses one cubic meter of space (Hannesson 1998) Thus, natural gas requires one thousand times more space than oil to provide the same energy content (at atmospheric pressure). Furthermore, natural gas requires special handling due to its gaseous rather than liquid form. The common methods for transporting natural gas is either in pipelines or in cooled-down liquefied form on special ships, usually referred to as Liquefied Natural Gas (LNG). Cooling down the natural gas reduces the volume greatly, but also requires quite expensive investments in plants where the gas is cooled down to a temperature of roughly -160 °C, as well as plants for re-gasification before distribution. This implies relatively large fixed costs for LNG, but in return the unit cost per distance is lower than for pipelines, which means that at large distances LNG is cheaper than pipeline transport. Another important aspect of pipeline transport is economies of scale in pipe sizes, as pipelines with a large diameter (which thus enables a larger flow volume) can achieve lower unit cost per distance than smaller pipelines. However, keep in mind that a larger pipeline can only be fully exploited if the volumes that need to be transported are large

[9] US statistics serve to illustrate this. In 2002 around 685 thousand short tons of coal were transported by rail compared to 113 by river, 138 by truck and 100 by tramway, conveyor or slurry pipelines (EIA 2004).

enough. Figure 2.2 compares transportation cost of various transport modes for natural gas, coal and crude oil.

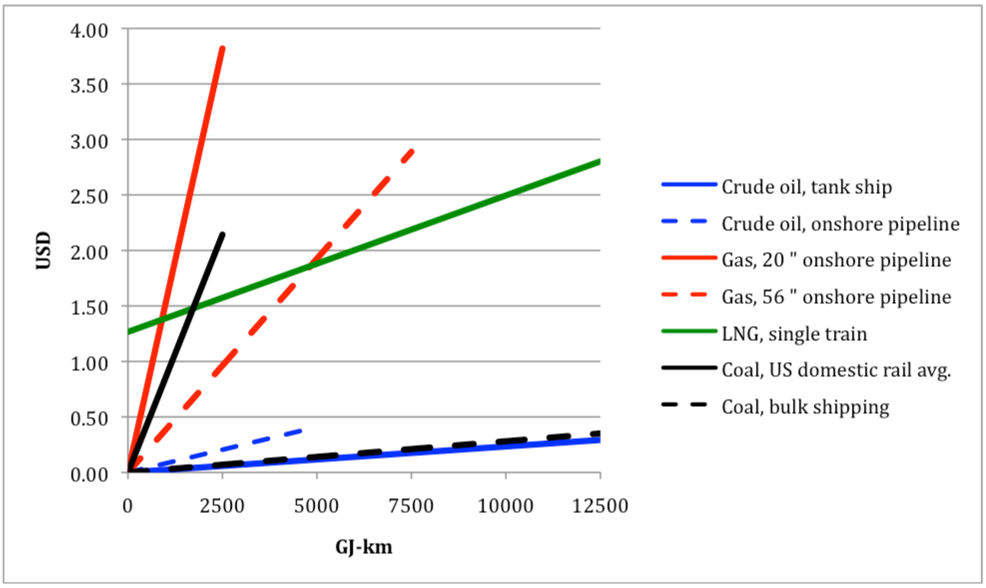

Figure 2.2: Comparison of transportation cost for various energy commodities, 2002 USD/GJ-km*. Sources: Jensen Associates (2009), EIA (2004). Unit conversion by the author. Crude oil tankers provide the cheapest transportation, followed by coal bulk shipping and onshore crude oil pipelines. The high fixed cost of LNG implies that gas pipeline transport is cheaper on shorter distances. Also observe that there are economies of scale in pipeline sizes.*

Additional factors that might limit geographical integration for natural gas are large up-front costs related to investments in infrastructure and the use of complicated long-term contracts of delivery. These factors limit the number of actors both on the demand and supply side and thus make competition less effective. Overall, it is logical to expect that coal and natural gas markets should be less geographically integrated than oil markets. However, that does not necessarily imply that coal and natural gas markets are *not* globally or internationally integrated.

I will now proceed to go through some of the characteristics of the geographical markets for oil, coal and natural gas. First, I will present some facts about the structure and composition of each individual market and then present the literature on market integration.

2.3.1.2 The global oil market

One of the most important characteristics of global oil markets is the extraordinary geographical imbalance between the areas that produce oil and the areas that consume it. Large consumers such as the United States, China and most EU countries have relatively little production and few national reserves, while roughly 1/3 of global annual production as well as almost 55 % of proven global reserves were concentrated in the Middle East in 2010 (BP 2011). The most important producers in the Middle East are Saudi Arabia, Iran, the United Arab Emirates, Iraq, Kuwait and Libya. Other countries with substantial production worldwide are Russia, Norway, Nigeria, Venezuela, the US and China. Note that although the two latter have substantial production, they are nevertheless large oil importers as consumption is much higher than production. The US accounted for 8.7 % of total world production in 2010, but consumed 21.1 %. China produced 5.2 % and consumed 10.6 % (BP 2011). The production and consumption of some important countries and regions are illustrated in figure 2.3.

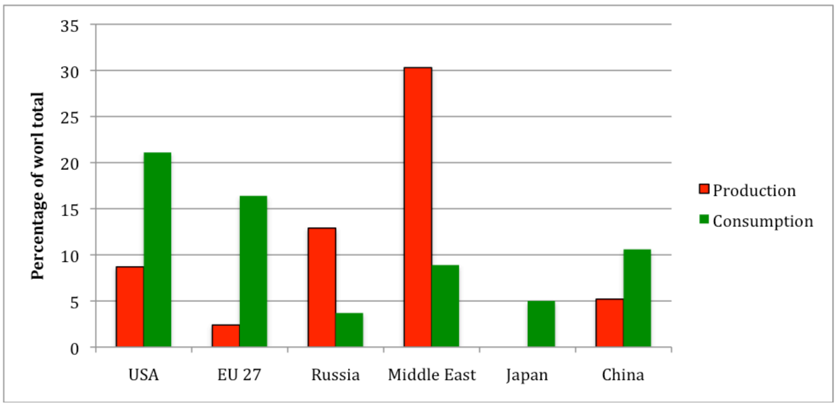

Figure 2.3: Important oil producers/consumers, percentage of world total. *Source: BP Statistical Review of World Energy 2011. The EU 27 consists of all the 27 EU member countries as of 2011.*

Another important aspect of global oil markets is the presence of the Organization of Petroleum Exporting Countries (OPEC), an international cartel consisting of 12 oil-producing countries[10]. It seeks to control quantities and prices on the world market, and has been an important force in oil markets since the Arab oil embargo of 1973. According to BP (2011), the OPEC member countries controlled roughly 77 % of the world's proven reserves in 2010[11], as well as 42 % of the production.

Traditionally there has not been much controversy in the academic literature about the belief that world oil markets are strongly geographically integrated. William Nordhaus (2009) wryly put it this way *"the concept of a single world oil market is not 100 percent correct, only about 99.8 percent correct"* (p. 1). Although there have been a few studies criticizing

[10] As of 2011 the OPEC members are Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates and Venezuela.

[11] Excluding Canadian tar sand.

this finding (e.g. Weiner 1991), the overall consensus within the economic literature has been that world oil markets are strongly integrated. This does not only apply geographically but also between different crude oil qualities and across different refined products (Adelman 1984, Rodriguez & Williams 1993, Asche, Gjølberg & Völker 2001, Bachmeier & Griffin 2006, Nordhaus 2009). However, note that during the first half of 2011 there has been an increasing divergence between the prices of the two most quoted benchmarks for crude oil; West Texas Intermediate (WTI) and Brent Blend[12] (The Economist, june 16. 2011). It is still too early to determine the reasons behind this divergence, but if it persists it will become more problematic to talk about oil markets being strongly globally integrated.

2.3.1.3 International coal markets – divided or integrated?

International coal markets are less transparent and less sophisticated than oil and natural gas markets, and therefore the knowledge about price behavior has been limited until recently (Zaklan et al 2011). Traditionally, the global coal market has been believed to be separated into at least two markets[13], the *Pacific market* and the *Atlantic market* (World Coal Institute 2009, Zaklan et al 2011), as shipping coal is considerably cheaper than transporting it over land. The Pacific market has the largest volume in production, consumption and trade (World Coal Institute, 2009). Furthermore, China is by far the world's largest coal producer and accounts for almost half of the world's annual production (48.2 % in 2010) (BP 2011). However, China's consumption is equally huge and therefore the country is a net importer on the balance.

While oil markets are geographically imbalanced with regards to production and consumption, coal markets are in fact remarkably *balanced*. As table 2.1 illustrates, most large coal consumers also have a relatively large production. Out of the six largest coal producers, four of them are also among the six largest consumers. If the list was expanded a little, it would show that Indonesia is also a relatively large consumer and South Africa a large producer. There are a few exceptions, most notably Japan and South Korea who import quite large quantities but have no reserves of their own, as well as Australia where production is considerably higher than consumption.

[12] Brent blend is the price of sweet crude oil from the Brent field in the North Sea. WTI is the price of West Texas Intermediate Crude Oil in Cushing, Oklahoma in the United States.

[13] According to Li (2007), some have also argued that there are three global coal markets: America, Europe and Asia-Pacific.

	Largest producers	Largest consumers
1	China (48.2%)	China (48.3%)
2	United States (14.8%)	United States (14.8%)
3	Australia (6.3%)	India (7.8%)
4	India (5.8%)	Japan (3.5%)
5	Indonesia (5.0%)	Russia (2.6%)
6	Russia (4.0%)	South Africa (2.5%)

Table 2.1: The world's six largest coal producers and consumers. *Source: BP Statistical Review of World Energy 2011. The percentage of worldwide total production/consumption is indicated in brackets.*

As China is by far the largest global consumer and producer of coal, the development in this country will be vital to future international coal markets. Therefore, a short discussion on China is warranted. First of all, it is quite clear from current trends and policies that China's consumption and production of coal will continue to grow in the years to come. Much of China's economic growth has been fueled by coal power; in recent years the proportion of primary energy from coal has been roughly 70 % (IEA 2008, BP 2011), and in the ten-year period from 2000 to 2010 China increased its annual production with almost 140 % (BP 2011). China has relatively small reserves of natural gas and oil, and although there are plans to substantially increase capacity within hydro and nuclear power[14], existing infrastructure (power plants, transportation systems and transmission lines) are largely based on coal power and are being expanded rapidly[15] (Ansolabehere et al 2010). Secondly, it is highly uncertain if China's domestic coal reserves can sustain a production rate as high as the current one in the long run. The current reserves to production (R/P) rate of China is 35, a figure that indicates that with its current production, domestic reserves are expected to last 35 years[16] (BP 2011). Thus it seems likely that international trade in coal markets will grow

[14] By 2020, China plans to increase its operational nuclear power capacity to 45-80 GWe, depending on the technology improvements realized (WNA 2011), and to increase hydropower capacity to 300 GW. Compared to current energy generation, these numbers imply increasing nuclear power 4 to 8 times and roughly a doubling of hydropower capacity.

[15] The only factor that could potentially reverse this trend is a global agreement on reduction of greenhouse gas emissions. However, such an agreement will be exceptionally difficult to reach and would take a substantial amount of time to implement, especially due to infrastructure issues.

[16] The R/P ratio is one of the most widely used indicators in energy markets. However, one should be careful when interpreting it for several reasons. First of all, annual production rates will not remain constant. As is the case with Chinese coal, they are likely to increase in the near future but later decline as coal becomes scarce and less economic to mine.

substantially in the future and that China will be an increasingly important export destination. With increased trade volume, probably coming from a multitude of exporters, it is also possible that this could function as a driver for increased geographical market integration.

Another factor that is important to consider in coal markets is that there is a significant quality difference between different types of coal in terms of energy content and purity. This must be taken into account when examining market integration, as the price of coal of similar quality in different locations should be examined if one is interested in isolating the effects of geographical price comovement. Price comovement across different quality types is also an interesting area of study, but will not be included in this chapter as it focuses on geographical relationships.

The notion of a globally divided coal market, split between the Atlantic and the Pacific has recently come under serious scrutiny, as several studies have found global coal markets to be more integrated than formerly believed. First among them, Wårell (2006) found that in the period 1980 to 2000 the import prices of steam coal and coke in Europe and Japan were cointegrated. She concluded that this supports the hypothesis of a single global coal market. However, when analyzing only the period from 1990 to 2000, steam coke markets in Japan and Europe were not cointegrated[17] (Wårell 2006). Li (2007) replicated the research of Wårell using export prices and a different set of countries and reached the conclusion that global coal markets are indeed generally integrated. Zaklan et al (2011) also examined global market integration in steam coal markets using newer data and higher frequencies than previously, and found both import and export markets to be well integrated worldwide with the notable exceptions of Columbian prices with any other price series as well as export prices between one Australian and Chinese location. Even though prices are cointegrated, some prices series still demonstrate rigidity (depending on which shipping route they are associated with) and poorly integrated areas still exist (Zaklan et al 2011). This notion is also

Secondly, the reserves used are resources economically recoverable under current conditions. This number may change due to discovery of new reserves, technological change (implying that more resources can be extracted or lower cost) or changes in coal prices. The size of China's coal reserves is a controversial topic, with large variations in estimates. However, even in spite of all these shortcomings, the R/P ratio can still serve as a rough indicator of how sustainable production is.

[17] This could be due to the lack of an actual price relationship or because of the relatively short time period examined. The substantial problems with using ADF or cointegration tests with few observations will be discussed in later chapters.

supported by Bachmeier & Griffin (2006) who found that coal prices at five different locations in the US were cointegrated, but the degree of market integration using error correction models was found to be quite low. The reason could perhaps be that the western parts of the US are associated with the Pacific market and the eastern US with the Atlantic market. Overall, the issue of exactly how well world coal markets are integrated remains somewhat unclear, although it is certainly reasonable to assume that the existence of a single global market is possible.

2.3.1.4 The international markets for natural gas

Gas markets are often divided into three major regional markets; *North America*, *Europe* (including the former USSR) and *Asia-Pacific* (Rosendahl & Sagen 2007). In terms of market size, the European market is the largest and accounted for almost 36 % of global consumption in 2011, while North America consumed around 27 % and Asia-Pacific nearly 18 % (BP 2011). In the European market, the EU is a very large importer and with the exception of the United Kingdom and the Netherlands it has almost no natural gas production of its own. Imports to the EU are mainly through pipelines from Russia, Norway and Algeria, as well as some through LNG from Nigeria and Qatar. The North American market is centered on the US, which has a substantial domestic production of almost 611 billion cubic meters of gas annually. This equals roughly 89 % of US consumption (BP 2011). Around 5 % of US production is exported to the populous provinces of Ontario and Quebec in Eastern Canada, while the remaining US consumption mainly is imported by pipeline from the Alberta region in Western Canada (BP 2011). Some minor trade flows also go from the US to Mexico and from Trinidad & Tobago to the US. While both the US and European markets are dominated by pipelines, LNG is by far the most important mode of transportation in the Asia-Pacific. In this market China, Japan, India and South Korea are the biggest consumers. However, since they have no natural gas resources of their own, Japan and South Korea are by far the largest importers and 65 % of all natural gas trade flows to countries in Asia-Pacific go to Japan or South Korea (BP 2011). The biggest exporters in Asia-Pacific are Indonesia, Malaysia and Australia, but large trade flows into this market also come from Qatar (the world's largest LNG exporter), the United Arab Emirates and Oman. Figure 2.3 and 2.4 shows an overview of the biggest global natural gas importers and exporters respectively. (Gas trade flows have been chosen instead of production and consumption figures to be able to display the proportions of pipelines and LNG in trade).

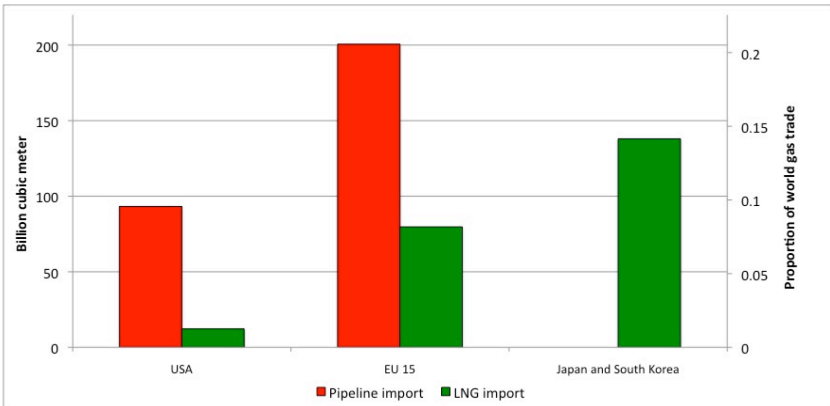

Figure 2.4: Major natural gas importers, flows by transport type[18].
Source: BP Statistical Review of World Energy 2011.

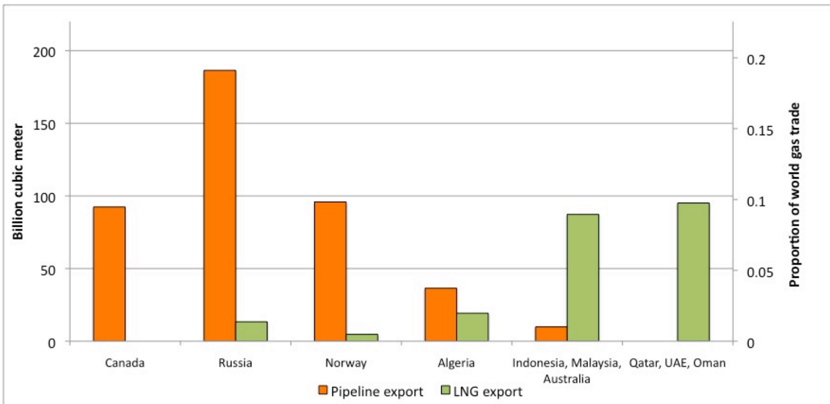

Figure 2.5: Major natural gas exporters, flows by transport type.
Source: BP Statistical Review of World Energy 2011.

Strong integration within the central European market was confirmed by Asche, Osmundsen & Tveterås (2000), who found that the European market is well integrated both on the national level and between countries[19]. However, some recent empirical research on market integration does not support the traditional notion of three geographical markets for natural gas. Silverstovs et al (2005) found European and Japanese markets to be cointegrated, which implies that there might be two global markets for natural gas instead of three. The same study also found no evidence for the European/Japanese market to be integrated with the American market, and confirmed earlier findings of strong integration within the US and European markets.

[18] The EU15 consists of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. The gas trade flows were calculated on a contractual basis and may not exactly equal physical flows.

[19] Specifically, Asche, Osmundsen & Tveterås (2000) found natural gas markets within France, Germany and Belgium to be well integrated both on the national level and with each other.

A possible cause for increased geographical integration in gas markets is that transportation cost for LNG has fallen sharply during the last decade, while trade volumes have increased dramatically (Rosendahl & Sagen 2007). Furthermore, although pipelines are the dominant form of transportation in both the North American and European market, LNG imports to the European market might be sufficiently large to cause market integration between Europe and Asia-Pacific. In 2011, the EU15 received around 28 % of its natural gas imports through LNG, a number has been growing rapidly in recent years (BP 2011). The reason is perhaps not only lower transport cost, but also Europe's wish to reduce dependency on Russian gas. In comparison to the EU15, the US only received 11.5 % of its gas from LNG, roughly half of which was from Trinidad & Tobago, a country that has relatively insignificant flows to Europe or Asia-Pacific (BP 2011). Qatar plays an interesting role in international natural gas markets, as the country is the largest LNG exporter in the world and delivered 36.2 billion cubic meters of natural gas to the Asia-Pacific and 35.8 billion cubic meters to Europe in 2011 (BP 2011). If Qatar maximizes its profit by sending LNG to the market with the highest price of the two (assuming flexibility to do this), that could be enough to keep prices reasonably close to each other. No other actor delivered more than 7 billion cubic meters to two of the three regional markets, with the exception of Russia with its massive pipeline export to Europe combined with an LNG export of 13.3 billion cubic meters of its east coast to Asia-Pacific. However, because of the vast geographical distance between central Russia and its Pacific coast, it is not certain that these two areas should be considered as part of the same natural gas market.

2.3.1.5 Summary of geographical market integration

Overall, the empirical findings on geographical integration in energy markets show that oil markets have historically been strongly integrated into one world market. Recent developments indicate that this could perhaps have changed, but it is still too early to tell. Coal and natural gas markets are historically less integrated than oil markets, but coal markets are integrated to a greater extent than natural gas markets. Furthermore, recent empirical evidence indicates that the presence of a single global coal market is quite likely. Nevertheless, some price rigidity does exist, as well as certain isolated areas with their own price behavior. However, due to the developments in China, it is reasonable to expect trade volumes in Asia-Pacific in general and exports to China in particular to keep growing, which could further increase international market integration in coal markets. Natural gas markets are divided into at least two geographical price areas consisting of the Americas and

Europe/Asia-Pacific, possibly three areas centered on Europe, North America and Asia-Pacific. The relative degree of market integration in oil, coal and natural gas markets is logical when comparing the transportation cost of the three commodities, but there might also be other factors limiting geographical integration for natural gas and coal, particularly infrastructure and contracting concerns.

2.3.2 Price comovement between energy commodities

Because of the multitude of fundamental relationships between different energy commodities, one would certainly expect to find long-term price relationships between them. Energy commodities are substitutes in a large amount of uses (e.g. natural gas, coal and fuel oil in electricity production, industrial use such as boilers or direct home heating[20]). Furthermore, crude oil and natural gas are often coproduced, and through the transportation of coal and natural gas, bunker fuel could perhaps be considered as an important input factor for these commodities (when import prices are used). Another aspect to consider is that energy commodities might respond similarly to external economic shocks. I will now provide a short overview of some of the available research on the price links between energy commodities.

Historically, oil and natural gas prices have been perceived as being quite closely related to each other and it has been common to link natural gas contract terms to the development in the oil price. The price relationship between natural gas in the Henry Hub[21] and the price of WTI has typically been in the range from 6:1 to 12:1[22] (Hartley, Medlock & Rosthal 2007, Strosse 2011). Although it has been common to contractually link oil and gas prices, there has also been much discussion about oil and natural gas prices decoupling as a consequence of various changes to the oil and gas industry (Hartley, Medlock & Rosthal 2007). Among the proposed reasons for prices decoupling are deregulation, the increased efficiency of natural gas power production resulting from the adaptation of combined cycle gas turbines

[20] According to Hartley, Medlock & Rosthal (2007), it is substitution in electricity generation that plays the most important role in influencing the relative prices between different energy commodities. Substitution may happen on the individual plant level (some plants may burn multiple types of fuel, e.g. natural gas and fuel oil) or on the grid level (by adjusting how intensely plants are operated).

[21] The natural gas price in the Henry Hub is the most quoted price for natural gas in the US.

[22] A 6 to 1 price relationship implies that one barrel of WTI crude oil is priced roughly 6 times higher than one million Btu of natural gas.

and recently the major discoveries of shale gas combined with a global drop in gas demand and high oil prices (Hartley, Medlock & Rosthal 2007, Strosse 2011).

Empirically, both Villar & Joutz (2006) and Hartley, Medlock & Rosthal (2007) have found that a stable long-term price relationship between Henry Hub gas prices and WTI prices in the periods 1989-2005 and 1990-2006 respectively. The same result was found by Panagiotidis & Rutledge (2007) for UK gas prices and the price of Brent Blend crude oil between 1996 and 2003.

To my knowledge there are no studies directly and thoroughly concerned with the empirical price relationship between coal and oil or that of natural gas and coal. However, two studies that also examined geographical market integration have touched upon the subject. The first, conducted by Bachmeier & Griffin (2006) examined market integration across oil, natural gas and coal markets. It concludes that although there are price linkages between the three, they are weak and it is not useful to imagine the existence of a primary energy market, except perhaps in the very long run (Bachmeier & Griffin 2006). The second conducted study, by Zaklan et al (2011), investigated the relationship between coal and fuel oil and found no evidence of market integration.

Overall, empirical evidence seems to indicate that although oil, natural gas and coal are substitutes in many uses both directly and on a system wide basis, it is not correct to consider these three commodities as part of one integrated energy market. However, some price comovement between the three certainly exists, in particular between oil and natural gas where fairly strong regional integration has been identified, e.g. in the US and UK.

2.4 Energy/non-energy commodity price comovement

There is a fairly limited amount of literature on energy/non-energy commodity price relations (Baffes 2009). Nevertheless, this section will provide an overview on some of the available research. First, the price linkage between energy and agricultural commodities will be presented, then industrial metals and finally precious metals. I will touch briefly upon which fundamental factors might cause the presence of price comovement, but this topic will be much more thoroughly discussed in chapter six.

2.4.1 Agricultural commodities

The price relationship between energy and agricultural products is complex and it is difficult to make a priori statements about how these prices may interact. Oil, natural gas and coal are important input factors in agricultural production and distribution and therefore a ceteris paribus increase in energy prices should imply an increase in the price of agricultural commodities, the extent of which would be determined by the energy intensity in the production of each particular crop (FAO 2002). Other possible price linkages may stem from the use of fertilizer and pesticides, macroeconomic factors or even substitution in those markets where natural fibers and rubber compete directly with synthetic oil based products (e.g. natural fibers and synthetic clothing, or rubber and plastic) (FAO 2002).

Another possible cause of price linkages is the relationship between fossil fuels and biofuels, among which bioethanol and biodiesel are the most important. These products are substitutes for oil and as oil prices change, farmers should respond by producing more or less biofuel crops, even though government policies also play a substantial role in determining the overall intensity. The most important crops for bioethanol production are corn (maize) and sugar, while biodiesel can be produced from a multitude of vegetable oils, among them rapeseed, sunflower, soybean, coconut and palm oil. Global production of ethanol for fuel and biodiesel is shown in figure 2.6. Observe that bioethanol production increased almost fourfold during the last 10 years; from ca. 20 billion liters annually in 2000 to almost 80 billion liters in 2009. Biodiesel production increased from a very small annual production around 2000 to almost 20 billion liters annually in 2009.

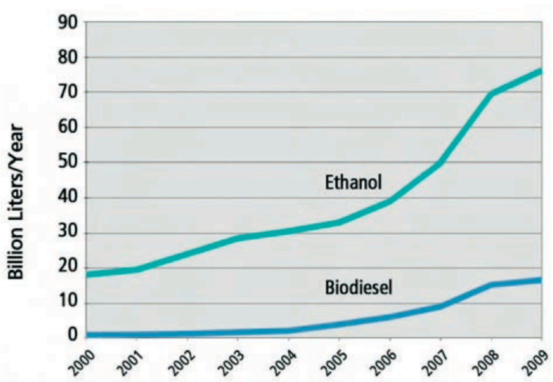

Figure 2.6: Global production of ethanol for fuel and biodiesel.
Graph from REN21 (2010).

It is also important to note that increased biofuel production may not only have an impact directly on the prices of biofuel crops, but also indirectly on other crops, as the amount of land allocated to producing them is changed. According to Mitchell (2008), American bioethanol production from corn has especially had an impact on soybeans, while European production of oilseeds has substantially displaced wheat production.

I will now proceed to look at some of the empirical findings on the relationship between energy and agricultural commodities, much of which was undertaken due to the food crisis of 2008. On the general level Baffes (2009) found a positive relationship between global energy and agricultural price indices, with a transmission price elasticity of 0.26. When the agricultural index was split into *food* and *beverages*, elasticities of 0.27 and 0.38 respectively were found and when looking even closer at the food category, elasticities of 0.28 for *cereals*, 0.29 for *edible oil* and 0.22 for *other foods* were established[23]. Based on these findings, as well as the analysis of other commodity types, Baffes (2009) writes *"as long as energy prices remain elevated, most non-energy commodity prices are expected to remain high"* (p. 9). Furthermore, Baffes & Haniotis (2010) conclude that *"a stronger link between energy and non-energy commodity prices is likely to have been the dominant influence on developments in commodity, and especially food, markets"* (p. 2).

The strong relationship between energy and fertilizer also plays an important role. On the fundamental level, it is very logical as nitrogen based-fertilizer is mainly produced from natural gas. Empirically, the relationship has been confirmed by Baffes (2009), who found the price transmission elasticity between the energy and fertilizer indices to be 0.55. This was the strongest relationship Baffes (2009) found between energy and any non-energy product. Thus, energy prices influence the prices of fertilizer, which again may influence agricultural markets since it is an important input factor.

Mitchell (2008) conducted an analysis of what were the main drivers of the large increase in international food commodity prices from 2002 to 2008. He concludes that increased biofuel production was responsible for 70-75 % of the increase, while the remaining 25-30 % can be attributed to increased energy prices and the weak US dollar (Mitchell 2008). Mitchell (2008) also points out that increased biofuel production was driven mainly by changes in US and EU regulation, not by energy prices.

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[23] Here is a further specification of what the different groups constitute. *Beverages*: coffee arabica, coffee robustica, cocoa and tea. *Cereals:* maize, rice, sorghum and wheat. *Edible oil:* coconut oil, groundnut oil, palm oil, soybean meal, soybean oil, soybeans. *Other foods:* bananas, beef, chicken, oranges, shrimp, sugar.

2.4.2 Industrial metals and minerals

There is very little empirical literature on the energy/industrial metals price link. The papers I have been able to find are concerned with energy and commodities in general and consider industrial metals and minerals as part of this analysis. First of all, Pindyck & Rotemberg (1990) found a significant long-term price relationship between crude oil and copper. Baffes (2009) also found a significant price elasticity of 0.27 between energy and metals and minerals price indices[24]. In an analysis of commodity price comovement, Lescaroux (2009) found particularly strong correlations between crude oil and industrial metals, but believes that *"the tendency of commodity prices to oscillate together reflects the tendency of their fundamental factors to move together."* (Lescaroux 2009: p. 3912). After taking account of inventory levels, which he states are the key to controlling for macroeconomic factors, the correlations between oil and industrial metals became quite weak and limited to the current month.

2.4.3 Precious metals

Pindyck & Rotemberg (1990) and Cashin, McDermott & Scott (1999) found crude oil and gold prices to be positively related[25]. Baffes (2009) also found a strong positive transmission elasticity between the energy and precious metals price indices (0.46). A very interesting detail is that this price elasticity was the second highest in the sample, it was only outdone by the energy-fertilizer elasticity (0.55) and much stronger than those between energy and food (0.27) or energy and metals and minerals (0.25).

Sari, Hammoudeh & Soytas (2010) examined how the prices of gold, silver, platinum and palladium relate to each other, as well as oil prices and dollar/euro exchange rates. Contrary to the previously cited studies, they conclude that there are no significant long-term price relationships between precious metals and oil[26]. They do find some short-term price relationships between oil and precious metals, in particular between oil and silver returns but

[24] The metals and minerals index included aluminum, copper, iron ore, lead, nickel, tin and zinc.

[25] I use the expression *"positively related"* instead of positively correlated or cointegrated, as neither of these terms would accurately describe the concordance method used by Cashin, McDermott & Scott (1999).

[26] The cointegration tests performed by Sari, Hammoudeh & Soytas (2009) have somewhat conflicting results, but overall they find stronger support for no cointegration than otherwise.

even though this relationship is significant, it only accounts for roughly 2 % of price movements.

2.4.4 Summary for energy/non-energy price relationships

I conclude this chapter with a summary of the main findings in the literature on price relationships between energy and non-energy commodities. Empirically, a relatively strong link between energy and agricultural products has been found in several studies (FAO 2002, Mitchell 2008, Baffes 2009). The link between energy commodities and industrial metals has, to my knowledge, not been extensively examined. Some studies include empirical testing of these relationships, but not as the main focus of the articles. Pindyck & Rotemberg (1990) and Baffes (2009) found significant and relatively strong price relationships, while Lescaroux (2009) only found a very weak relationship after controlling for macroeconomic factors. For precious metals, several studies indicate a significant relationship with energy (Pindyck & Rotemberg 1990, Cashin, McDermott & Scott 1999, Baffes 2009), however Sari, Hammoudeh & Soytas (2010) found no such relationship.

3. Methods

"(...) the tale of the drunk and her dog offers a reminder to applied statisticians that the cointegration relationship is not merely a statistical convenience with no behavioral content." – Michael Murray

In this chapter I will go through the methods that will be used in the econometric analysis in chapter 5. All methods are within time-series econometrics.

3.1 Stationarity

A critical factor to consider when conducting an analysis based on time-series data is whether the data are stationary or non-stationary (have a unit root). While stationary data series have a constant mean and variance, the probability structure of non-stationary series changes over time. This can lead to spurious regressions and implies a breakdown of traditional inference theory such as t-tests and F-tests (Granger 1986, Gordon 1995). Therefore, determining if the data are stationary is a vital first-step in time-series econometrics. A standard test for non-stationarity is the Augmented Dickey Fuller (ADF) test (Dickey & Fuller 1979). For each price series P_t the test statistic is measured by the following regression:

$$\boldsymbol{\Delta P_t = \alpha + \mu t + \beta P_{t-1} + \gamma_1 \Delta P_{t-1} + \ldots + \gamma_k \Delta P_{t-k} + \varepsilon_t} \qquad \textbf{(Equation 3.1)}$$

Δ is the difference operator, while t is a time trend and k denotes the number of lags. The test should be run both with and without a time trend and with a varying number of lags. An intercept α is included when the time series has a mean different from zero, which is normally the case in economic time series. The null hypothesis is that each price series is non-stationary (H_0: $\beta = 0$), while the alternative hypothesis is that the price series is stationary (H_A: $\beta < 0$). The null hypothesis is tested against the ADF statistic of β in equation 3.1.

If the null hypothesis is rejected, the price series is said to be stationary or integrated of degree zero, i.e. $P_t \sim I(0)$. In this case normal regression techniques may be applied. If the null hypothesis is not rejected, the ADF test is repeated on the first differences of the price series, now with the null hypothesis that the first differences are non-stationary. If the null hypothesis is rejected at this point, the price series is integrated of degree one, $P_t \sim I(1)$. A failure to reject H_0 again implies that the time series is integrated of degree two (or higher), which is rare for economic time series. In general, if it takes *n* differentiations for a time-series to become stationary it is said to be integrated of degree *n*, $P_t \sim I\ (n)$.

3.1.1 Optimal lag length in the ADF test

The choice of the amount of lags (*k* in equation 3.1) in the test is a tradeoff between reducing bias from serial correlation in the error terms (by including more lags) and increasing the power of the test (by including fewer lags). Monte Carlo experiments have showed that it is better to error on the side of including too many lags than too few. In practice, there are several ways of choosing the appropriate amount of lags. One practical rule of thumb is to start with a generous number of lags and remove the lags that are individually insignificant according to a standard student-t test (Banjeree et al 1993). Another common method for choosing the amount of lags is to apply an information criterion such as the Schwartz or Akaike information criterion (AIC) (Gordon 1995). In this paper I will use the AIC, which can be described by the following equation:

$$\mathbf{AIC = ln\ (\sigma^2) + 2k/T} \qquad \textbf{(Equation 3.2)}$$

Where σ^2 is the variance of the estimated residuals. *T* is the number of parameters and *k* the sample size.

However, a very important aspect pointed out by Gordon (1995) is that different conclusions about stationarity may be reached depending on which method is used to select the number of lags. The reason is that the different methods do not necessarily provide the same recommendations regarding optimal lag length (Gordon 1995). Therefore, the empirical researcher should be cautious and examine if the result of the ADF test is sensitive to the chosen amount of lags. This can be done either by testing if different methods of choosing the optimal lag length yield different conclusions (see e.g. Gordon (1995) or Wårell (2006)) or simply examining if the conclusion varies within a relevant window of lag lengths (Gordon 1995).

3.2 Cointegration

When analyzing the relationship between time-series it is important to consider the long-term relationship between them. Two series are cointegrated if a linear combination of the two is integrated at a lower level than the two series individually. The most common example would be two series individually integrated of degree one with a linear combination of the two integrated of degree zero. In this case, some influence on the price generating processes implies that the two price series are bound together in the long-term, although they may deviate in their relationship in the short-term.

Two standard ways of testing for cointegration is Engle and Granger's two-step procedure (Engle & Granger 1987) and Johansen's cointegration test (Johansen 1988). The first is used to test the cointegration relationships between pairs of time-series, while the latter can be used to for both multivariate and bivariate cointegration tests. I will apply Engle & Granger's two-step procedure in my empirical analysis. To use this method, the relationship between the two variables must either be defined on the basis of economic theory (unrestricted cointegration test) or estimated through a regression (restricted cointegration test). This is the "first step" of Engle & Granger's two-step procedure. I will use a restricted cointegration test, which is based on a regression of the following form:

$$\mathbf{y_t = \beta x_t + \varepsilon_t} \qquad \textbf{(Equation 3.3)}$$

where y_t and x_t are the two variables being examined and ε_t is the error term. A constant and/or a trend may also be added. Rearranging equation 3.3 we get:

$$\mathbf{\varepsilon_t = y_t - \beta x_t} \qquad \textbf{(Equation 3.4)}$$

Consequently, an ADF-test of the error term in equation 3.3 can be used to test if the two variables y and x are cointegrated. This is the "second step" of the two-step procedure. If the error term is found to be stationary, the two variables in question are cointegrated with a vector $[1, -\beta]$.

If a trend and/or constant is used when estimating the cointegration relationship, this should not be used in the ADF test, i.e. a deterministic component may be added to either equation 3.1 or 3.3 but not both. Furthermore, it is important to keep in mind that the normal critical values for the ADF test cannot be applied to restricted cointegration tests. Instead the test statistics should be compared to critical values specifically calculated for this purpose. MacKinnon (1991) provides a table that is frequently used.

4. Data and descriptive statistics

"When the going gets tough, the tough get empirical" – Jon Carroll

I have chosen to do quantitative testing of the relationship between crude oil and six agricultural commodities, four industrial metals/minerals and two precious metals. In this chapter I give an explanation of the motivation behind my selection of commodities, data and time periods. I will then provide descriptive statistics, while the main econometric analysis will be presented in chapter 5.

4.1 Motivation behind selection of commodities and data

An empirical investigation of price comovement across international commodities must take geographical distances into account. When testing whether energy prices in location A move together with commodity prices in location B, one is making a joint hypothesis: 1. energy prices in location A and location B move together and 2. energy and commodity prices in location B move together.

To minimize this problem, I have chosen to use crude oil prices instead of coal or natural gas prices, since crude oil markets are geographically stronger integrated than the other two. This is not an entirely unproblematic choice, as both natural gas and coal play a larger role than oil in manufacturing of food and metals (EPA 2007). However, oil does play the most important role in transport and it is still the most important global energy commodity. Alternatively, one could use an energy price index weighted between oil, natural gas and coal (Baffes 2009). However, I still prefer to use only one energy commodity, as it is a cleaner approach and I find the geographical issues to be of higher importance than the industrial.

When choosing a price series for crude oil, there are many alternatives based on location and quality. Assuming that global oil markets indeed are strongly integrated, as they have been for the most of the period prior to 2011, it should not really matter greatly which price series one chooses. However, picking a price series from a high volume location can only be an advantage. I have chosen to use the price series for light sweet crude oil from the Brent field in the North Sea, the so-called Dated Brent Blend due to its prominent position in global oil markets. Another good candidate would have been the price of WTI.

For the agricultural commodities I have chosen *rice, wheat, soybeans, corn, sugar* and *palm oil*. The first five are all among the world's six most important agricultural commodities by value, as illustrated in table 4.1. Palm oil has been included in the analysis due to its important role both in food and biodiesel production. Among industrial metals/minerals I have chosen *aluminum*, *copper*, *iron ore* and *tin*. Aluminum, copper and tin are relatively energy intensive metals, while iron ore is a mineral that serves as the raw material for iron and steel production. Among precious metals, I have chosen the two most important, namely gold and silver.

Rank	Crops	Value (billion USD)
1	**Rice (paddy)**	**136**
2	**Wheat**	**83**
3	**Soybeans**	**47**
4	**Corn (maize)**	**40**
5	Potatoes	38
6	**Sugar Cane**	**35**

Table 4.1 Global crop production by annual value, 2008 billion USD.
Source: FAOSTAT database

After choosing commodities, the data type has to be selected. For the kind of problem statement that I have, time series data are the most appropriate, but I still need to select data frequency. When deciding on the frequency of data one faces the tradeoff of choosing a high frequency and dealing with a lot of "noise" or choosing a low frequency and needing to go further back in time to obtain a sufficient number of observations. In my case, I could have chosen annual, monthly, weekly or perhaps even daily time series data[27]. Annual data contain the least amount of noise and when using a frequency this low, problems of non-stationarity may be avoided (Baffes 2009, Baffes & Haniotis 2010). However, using an annual frequency requires you to go exceedingly far back in time to obtain a sufficient number of observations, preferably well more than 100 years (Pindyck 1999). I chose to use monthly time series, because I am interested in price relationships that are relatively "new",

[27] Annual and monthly commodity data are available online through the IMF, weekly data through Datastream.

but without the degree of noise found in weekly or daily data. Monthly time series is also the data type that is easiest to obtain and most commonly used in commodity price comovement research. This enables me to compare the findings with other studies more easily. Monthly data for my price series were obtained from the historical commodity database at indexmundi.com, which again collects the data from institutions such as the IMF, the World Bank, IEA and EIA. A detailed description of each variable is included in the appendix.

Commodities and data type having been chosen, one more vital choice has to be done, namely which time period(s) to investigate. Pindyck (1999) provides a rule of thumb for how many observations an ADF test needs to successfully reject non-stationary based on the nature of the underlying price generating process[28]. According to Pindyck (1999) a mean reverting price process with a half-life of five periods (in my case months) will require 120 observations to reject non-stationarity at the 5 % level. With fewer observations one will falsely conclude that the price series is a random walk. Following the same rule of thumb, a mean reverting process with a half-life of *three* and *ten* periods would require *73* and *241* observations respectively, to distinguish it from a random walk.

Even though these problems are important, I also want to examine if there are any new relationships in the data that could not be found in older datasets. The presence of new relationships is plausible due to the general increase in both price level and volatility that can be observed in many commodity markets after ca 2000, as well as the relatively dramatic increase in the use of biofuels that has taken place the last 10 years and the possible impact this could have on the energy/agriculture relationship.

To try to take both of these matters into account I have chosen to analyze two time periods. The first time period goes as far back as I could obtain complete time-series for all the commodities and thus runs from January 1982 to December 2010 for a total of 348 observations. The second period runs from January 2000 to December 2010 for a total of 132 observations. Using Pindyck's simple rule of thumb again, the number of observations for the entire period should be enough to make the right conclusion about a mean reverting price

[28] Pindyck derives this number by looking at a simple ADF regression with the form $\boldsymbol{\Delta P_t = \beta P_{t-1} + \varepsilon_t}$
The asymptotic standard deviation of this equation is: s.d. $(\beta) = ((1-\beta^2)/T)^{1/2}$, where *T* is the number of observations. To test whether $\beta \leqq x$ at the 5 % level a t-statistic of at least 2.89 is needed.
Thus, $2.89^2 \leqq T\,(1-\beta)^2/1-\beta^2$ and conversely $T \leqq (8.352*1-\beta^2)/(1-\beta)^2$.
Some examples of β values for different mean reverting price processes:
3 years half-life: β = 0.794, 5 years half-life: β = 0.87, 10 years half-life: β = 0.93.

generating process with a half-life of more than 14 months at the 5 % significance level. For the shorter, the maximum half-life is slightly more than five months, which might seem too little. However, keep in mind that applying cointegration analysis to time series with 100-130 observations is common in the price comovement literature (perhaps unfortunately?). Also, remember that the ADF model being applied (equation 3.1) is larger than the simple model in Pindyck's example. The point is not to calculate the exact number of observations needed when assuming different kinds of mean reversion, but to illustrate the problems of concluding based on relatively few observations. The implication is that caution is needed when interpreting the analysis of the shorter period. After having motivated the choice of commodities, data and time periods, I will now present descriptive statistics.

4.2 Descriptive statistics

I will present descriptive statistics and stylized facts for the level and first differenced data in both periods. Since I have included a relatively large number of variables, they will be divided into two groups. The first is crude oil and agricultural products while the second includes the industrial and precious metals. This way of presenting the data makes it easier to compare the two periods, but more difficult to compare the commodities in the two groups. Keep in mind that roughly 1/3 of the observations from the long period are overlapping with the observations from the short period. When referring to time periods, I will use the notation *year:month* for convenience. January 1982 is thus 1982:1.

ENTIRE PERIOD (1982:1 – 2010:12) – LEVEL DATA							
	Crude oil	**Corn**	**Wheat**	**Rice**	**Soybeans**	**Sugar**	**Palm oil**
Mean	32.6	119.1	162.1	297.5	246.7	10.0	433.9
SD	22.9	35.5	52.0	122.5	71.6	4.1	187.4
Low	9.6	65.4	101.8	162.1	158.3	2.8	162.8
High	133.9	287.1	439.7	1015.2	554.2	31.1	1171.2
Coeff of Variation	**0.70**	**0.30**	**0.32**	**0.41**	**0.29**	**0.41**	**0.43**
AFTER 2000 (2000:1 – 2010:12) – LEVEL DATA							
	Crude oil	**Corn**	**Wheat**	**Rice**	**Soybeans**	**Sugar**	**Palm oil**
Mean	52.4	132.0	187.7	340.7	275.0	11.3	506.5
SD	26.3	47.0	69.7	182.7	100.0	5.3	240.7
Low	18.6	75.1	105.1	162.1	158.6	5.1	185.1
High	133.9	287.1	439.7	1015.2	554.2	31.1	1171.2
Coeff of Variation	**0.50**	**0.36**	**0.37**	**0.54**	**0.36**	**0.47**	**0.48**

Table 4.2: Descriptive statistics of level data, crude oil and agricultural products.
Coefficient of variation = SD/Mean.

Two interesting observations can be made from table 4.2. First of all, the mean of *all commodities* is higher in the period after 2000 than in the entire period 1982-2010. Since these data are nominal, higher prices in the later time period is to be expected and further analysis is needed to determine if this would also be true with real prices. However, considering the size of the differences it certainly appears to have been a general price increase. Secondly, the coefficient of variation[29] indicates that the volatility of all the agricultural products is higher in the second period. The coefficient of variation of crude oil is higher in the long period than in the short, but this might be partially due to the low mean caused by the relatively low oil prices before 2000.

ENTIRE PERIOD (1982:1 – 2010:12) – LEVEL DATA						
	Aluminum	**Copper**	**Iron ore**	**Tin**	**Gold**	**Silver**
Mean	1634.9	2879.4	45.3	8475.5	450.6	739.4
SD	494.2	1942.3	35.8	4381.1	221.2	413.1
Low	918.9	1272.1	24.3	3698.4	256.1	364.4
High	3578.1	9152.9	212.0	26237.0	1390.6	2937.3
Coeff of Variation	0.30	0.67	0.79	0.52	0.49	0.56
AFTER 2000 (2000:1 – 2010:12) – LEVEL DATA						
	Aluminum	**Copper**	**Iron ore**	**Tin**	**Gold**	**Silver**
Mean	1912.2	4255.0	72.0	10039.0	586.2	980.2
SD	514.5	2531.0	47.1	5830.7	309.9	547.7
Low	1283.5	1377.4	28.8	3698.4	260.5	412.4
High	3067.5	9152.9	212.0	26237.0	1390.6	2937.3
Coeff of Variation	**0.27**	**0.59**	**0.65**	**0.58**	**0.53**	**0.56**

Table 4.3: Descriptive statistics of level data, industrial and precious metals.
Coefficient of variation = SD/Mean.

For the metals and minerals, all of the nominal prices are again higher after 2000 compared to the long period. In terms of coefficients of variation, there are no clear trends. I will now present descriptive statistics for the first differenced data in logarithmic form (DLog).

[29] Since the prices of the commodities vary significantly it would not be appropriate to directly compare standard deviations across commodities and periods. However, the coefficient of variation shows standard deviation as a percentage of mean and thus enables comparison.

ENTIRE PERIOD (1982:1 – 2010:12) – FIRST DIFFERENCES							
	Crude oil	**Corn**	**Wheat**	**Rice**	**Soybeans**	**Sugar**	**Palm oil**
Mean	0.0027	0.0023	0.0017	0.0013	0.0017	0.0013	0.0030
SD	0.0904	0.0582	0.0572	0.0633	0.0572	0.0633	0.0823
Skewness	0.01	-0.32	0.33	1.22	0.33	1.22	-0.14
Excess kurtosis	2.78	3.80	2.47	8.41	2.47	8.41	1.76
Normality test	69.63++	99.68++	51.51++	140.92++	51.51++	140.92++	33.64++
AFTER 2000 (2000:1 – 2010:12) – FIRST DIFFERENCES							
	Crude oil	**Corn**	**Wheat**	**Rice**	**Soybeans**	**Sugar**	**Palm oil**
Mean	0.0100	0.0080	0.0083	0.0064	0.0079	0.0125	0.0100
SD	0.0853	0.0638	0.0694	0.0664	0.0685	0.0843	0.0853
Skewness	-0.32	-0.53	0.28	2.49	-0.74	-0.19	-0.32
Excess kurtosis	2.08	1.94	1.90	13.88	2.17	0.18	2.08
Normality test	19.63++	15.01++	17.76++	61.86++	15.06++	1.35	19.63++

Table 4.4: Descriptive statistics for first differences, crude oil and agricultural products.
Mean significantly different from 0: ** at the 10 % level, ** at the 5 % level or *** at the 1 % level.* ***Normality rejected:*** *+ at the 5 % level or ++ at the 1 % level.*

None of these commodities have mean returns significantly different from zero in either the long or the short period. All the commodities have positive excess kurtosis, meaning the distributions are less concentrated around the mean than the normal distribution and have fat tails. The price series for rice is positively skewed to a relatively large degree, which implies that the right tail of the distribution is longer than the left. Otherwise there do not appear to be any distinctive patterns in skewness, some price series are negatively and some are positively skewed and this also varies according to period. Normal distribution is rejected for crude oil and all the agricultural commodities in both periods, with the exception of sugar after 2000.

ENTIRE PERIOD (1982:1 – 2010:12) – FIRST DIFFERENCES						
	Aluminum	**Copper**	**Iron ore**	**Tin**	**Gold**	**Silver**
Mean	0.0022	0.0050	0.0050	0.0014	0.0037*	0.0037
SD	0.0588	0.0660	0.0581	0.0567	0.0389	0.0669
Skewness	-0.59	-0.42	5.54	-0.68	0.27	-0.17
Excess kurtosis	3.36	4.01	53.87	3.39	2.69	2.16
Normality test	65.65++	100.76++	1196.80++	60.04++	60.77++	45.94++
AFTER 2000 (2000:1 – 2010:12) – FIRST DIFFERENCES						
	Aluminum	**Copper**	**Iron ore**	**Tin**	**Gold**	**Silver**
Mean	0.0032	0.0125*	0.0143*	0.0115*	0.0121***	0.0131**
SD	0.0552	0.0765	0.0883	0.0661	0.0386	0.0688
Skewness	-0.82	-1.00	3.86	-0.43	-0.27	-0.60
Excess kurtosis	1.71	4.89	23.13	1.26	0.93	1.58
Normality test	13.23++	36.51++	279.97++	9.07+	6.48+	11.21++

Table 4.5: Descriptive statistics for first differences, industrial and precious metals.
Mean significantly different from 0*: * at the 10 % level, ** at the 5 % level or *** at the 1 % level.* ***Normality rejected****: + at the 5 % level or ++ at the 1 % level.*

Gold is the only commodity with a mean return significantly different from zero in the long period. In the short period the price series for copper, iron ore, tin, gold and silver all have significant mean returns. All of the metals and minerals also have positive excess kurtosis. The price series for iron ore is considerably skewed to the right, while most of the other series are slightly skewed to the left. Normality is rejected for all return distributions in both periods.

5. Econometric Analysis

"The master economist [...] must understand symbols and speak in words" - John Maynard Keynes

In this chapter I will conduct an econometric analysis of the long-term price links between crude oil and the selected non-energy commodities. First, I will start by examining the stationary properties of the data using an ADF test. Then I will examine the long-term price relationships between crude oil and the various agricultural commodities and metals using Engle & Granger's two-step procedure for cointegration.

5.1 Stationarity

A price series does not have to be strongly stationary or strongly non-stationary, it may vary over time. Therefore, I will conduct an ADF test of both the entire period (1982:1-2010:12) and the time period after 2000 (2000:1-2010:12). Table 5.1 shows the results of the ADF test for the longer time period. The results are shown both with and without a trend, and the optimal number of lags was chosen using AIC.

VARIABLE	*LEVEL VALUES*		*FIRST DIFFERENCES*	
	Constant +trend	*Constant*	*Constant +trend*	*Constant*
Crude oil	-1.70	-0.16	-9.33**	-9.20**
Corn	-2.26	-1.69	-7.18**	-7.11**
Wheat	-2.79	-1.85	-7.53**	-7.47**
Rice	-2.14	-1.53	-12.28**	-12.26**
Soybeans	-1.96	-1.33	-11.26**	-11.24**
Sugar	-0.45	0.27	-11.45**	-11.44**
Palm oil	-2.24	-1.46	-4.80**	-4.75**
Aluminum	-3.20	-2.68	-5.39**	-5.40**
Copper	-1.44	1.00	-5.20**	-5.04**
Iron Ore	-0.45	0.96	-13.34**	-13.09**
Tin	-0.41	-0.06	-9.13**	-8.88**
Gold	2.63	4.45	-14.88**	-14.08**
Silver	1.30	2.48	-9.73**	-8.94**

Table 5.1: ADF test results for the entire period (1982:1 to 2010:12).
H_0: Non-stationary against H_A: Stationary
Critical values with constant and trend: 5 % = -3.43 and 1 % = -3.99
Critical values with a constant: 5 % = -3.87 and 1 % = -3.45
** Significance at 5 % level, ** Significance at 1 % level.*

Observe in table 5.1 that all variables are non-stationary and integrated of the same order, i.e. I (0). Thus, cointegration is an appropriate method to examine the long-run price relationships between these variables.

As explained in the methods chapter, using a different method than AIC to select the number of lags could result in a different conclusion about the properties of the data. Therefore I examined the sensitivity of the conclusion to the selection of lag length, both with and without a trend. For crude oil, corn, soybeans, sugar, palm oil, copper, iron ore, tin, gold and silver the conclusion of non-stationarity was valid for all the lag lengths tested. The level value price series for rice was found to be stationary when only one lag was used, the same was true for the aluminum series when five lags were used and for the wheat series with five and six lags. No first differences were found to be non-stationary for any price series. Some additional caution is thus warranted when interpreting the results for rice, aluminum and wheat.

After having performed an ADF test on the long period (1982:1-2010:12) I did the same for the short period (2000:1-2010:12), as I wanted to test this period separately to examine if there were any "new" relationships compared to the longer period. For the short period, the null hypothesis of non-stationarity for crude oil, iron ore and tin was rejected at the 5 % level when including a time trend, but not when only including a constant. In addition, the first differences for copper appeared to be non-stationary when a trend and constant was included. These results imply that that it is uncertain whether the price series for crude oil, tin and iron ore are non-stationary and whether the price series for copper is integrated at degree one or higher. Thus, these price series are *not* suitable for a cointegration test. All other price series were found to be non-stationary and integrated of degree one.

Iron ore, tin and copper could just have been excluded from the analysis. However, since crude oil is the explanatory variable in the regression used in the "first step" of Engle & Granger's two-step procedure (equation 3.3), these results thwart the entire plan of performing a cointegration test of the short period. The reason could be too few observations, as stated by Pindyck (1999) and discussed in section 4.1. A table describing the full results of the ADF test for the short period can be found in the appendix.

Of course, there is also a possibility that the underlying price generating processes for the price series shown in table 5.1 are not random walks, but instead mean reverting. In that case the later findings in this chapter might be based on an incorrect assumption. However, with the relatively large amount of observations and the quite strong significance of the results, it is very likely that the conclusion of non-stationarity is correct. A random walk price generating process is also the most commonly found in the literature when time series with a frequency higher than annual data are used.

5.2 Examining long-term price relationships

To examine the long-term relationships between commodity prices, I will apply cointegration analysis on the long period (1982:1-2010:12). The results are shown in table 5.2 below. I did not use a constant or trend when estimating the restricted cointegration relationship between crude oil and the various other variables, and thus I will use a constant in the ADF test of the error term. I will display results both with and without a trend component.

VARIABLE	***STATIONARITY OF ERROR TERM***	
	Constant +trend	*Constant*
Corn	**-3.05**	**-3.09**
Wheat	-3.26*	-3.27*
Rice	-3.49*	-3.49*
Soybeans	-3.65*	-3.37*
Sugar	**-2.34**	**-2.22**
Palm oil	**-3.06**	**-3.07**
Aluminum	-3.49*	-3.52*
Copper	-3.71*	-3.64*
Iron Ore	**-1.40**	**-1.28**
Tin	**-0.70**	**-1.57**
Gold	**-0.83**	**-1.04**
Silver	**-1.39**	**-1.85**

Table 5.2: Cointegration analysis with crude oil as explanatory variable.
H_0: Not cointegrated against H_A: Cointegrated
Critical values of test statistic from MacKinnon (1991): 5 % = -3.25 and 1 % = -3.78
** Significance at 5 % level, ** Significance at 1 % level.*

The agricultural commodities *corn*, *sugar* and *palm oil* are cointegrated with crude oil, while wheat, rice and soybeans are not. Among the industrial metals/minerals, the relatively energy intensive metals aluminum and copper are not cointegrated with crude oil, while *iron ore* and *tin* are. Both precious metals, *gold* and *silver*, are cointegrated with crude oil.

None of the original price series for the variables found to be cointegrated with crude oil were sensitive to the number of lags in 5.1. However, since testing for cointegration using Engle & Granger's two-step procedure also relies on an ADF test of the error terms, it is necessary to examine the sensitivity of the lag length again. I will limit the examination to those variables where a cointegration relationship was found. While the ADF test recommends seven lags for crude oil/corn, selecting four, three or two lags would lead to a different conclusion as the level data are found to be stationary with these lag lengths. Crude oil/iron ore is also a problematic price series, where selecting from zero to five lags indicates that the level price series is non-stationary while any lag length higher than five gives a stationary result (AIC recommends seven lags). For palm oil there was also a minor problem; the ADF test recommends three lags, while four lags with a trend indicates non-stationarity of the level data (all other lag lengths indicate stationarity). The conclusion of cointegration between crude oil and sugar, tin, gold and silver is insensitive to the choice of lag length.

6. Discussion

"Everything is related to everything else" - Barry Commoner

In this chapter the results of the econometric analysis will be compared with the findings in the literature on price relations between energy and non-energy commodities. I will also discuss the problem of establishing causality and determining what factors bring about long-term price relationships, as well as how the presence or absence of various causal factors fit with the empirical findings in the literature and my own analysis.

6.1 Results of analysis compared to the literature

The price relationships found between energy and agricultural commodities are compatible with those of Mitchell (2008), Baffes (2009) and Baffes & Haniotis (2010). Baffes (2009) found a cereals index and an edible oil index to be cointegrated with an energy price index, while Mitchell (2008) found the energy price to have a significant impact on food prices. However, these studies all used more aggregated data, i.e. they examined indices and not individual price series, and thus, it is difficult to make a precise comparison of the findings.

The results among the minerals are partly compatible to what has been found in the literature, as Baffes (2009) found a significant long-term price relationship between energy and metals indices. However, Pindyck & Rotemberg (1990) found a significant relationship between crude oil and copper, something that did not appear to be present in my dataset. Lescaroux (2009) found very strong price relationships between crude oil and aluminum, copper and iron ore, as well as a weak relationship between crude oil and tin. However, he attributes these relationships to macroeconomic factors and after controlling for inventory levels, only weak short-term price relationships persist. It was also interesting to evidently find a long-term price relationship between crude oil and iron ore. Iron ore is a mineral that is still unrefined, so one would expect energy as an input factor to play less of a role here than for the processed metals such as aluminum and copper. However, the crude oil/iron ore result was very sensitive to the lag length selected and too much emphasis should not be put on it.

Both gold and silver were cointegrated with crude oil, with no sensitivity to the lag length of the cointegration tests. These results are relatively strong, and in line with the findings of

Pindyck & Rotemberg (1990) and Cashin, McDermott & Scott (1999), who both found a significant long-term relationship between gold and crude oil. They also correspond to the findings of Baffes (2009), where a strong relationship between energy and precious metals indices was identified. However, they do not correspond to the findings of Sari, Hammoudeh & Soytas (2010) who found a short-term relationship between crude oil and silver, but no long-term relationships between crude oil and any precious metal.

6.2 Fundamental causal relationships

The theoretical foundations behind long-term commodity price comovement vary according to situation and this strongly affects the discussion on causality. When examining long-term price relationships between reasonably homogenous commodities in different locations or between different qualities of the same product, the fundamental economic relationship behind can very sensibly be assumed to be substitution. A power plant might as well buy energy commodities from one location as the other, as long as the price including transaction cost is not higher. The fairly uncomplicated theoretical foundation of price comovement over space or across different qualities of the same commodity is reflected in the literature, as the studies within this field are mostly concerned with determining the *presence* of long-term price relationships and seldom attempt to control for other factors outside of including a time trend. The same logic applies in part to long-term price relationships between different kinds of energy commodities, but not as strongly. Substitution is the most likely reason for price comovement, although there might also be other factors involved.

However, when examining long-term price relationships between energy and non-energy commodities, the question of what may cause the relationship is much more open. Even though the literature on price comovement across commodities is relatively limited, it still contains a multitude of model specifications and theories and many authors seem convinced that *their* method or model specification is the correct one (see e.g. Cashin, McDermott & Scott 1999 or Lescaroux 2009). Disentangling the multitude of factors within production, consumption, financial markets and macroeconomics that may cause price comovement is beyond the scope of this thesis and my ability. Even if one found variables that could be used to quantitatively separate the proposed causal factors, the non-stationary properties normally found in the data make traditional and well-tested methods such as multiple OLS regression unsuitable. Even though much progress has been made with methods such as cointegration, error correction models and Granger causality, there is still some disagreement about which methods are best suited for non-stationary data (Barret 1996, Cashin, McDermott & Scott 1999, Lescaroux 2009). Nevertheless, a discussion on causal factors is absolutely necessary.

To make the discussion more stringent I will structure it according to each proposed causal relationship, and I will also display visual illustrations of them to provide a better overview. Please keep in mind that the presence of one relationship certainly does not exclude the presence of others and that I am not arguing that all of these price linkages necessarily exist. The exact relationships between factors in terms of feedback effects etc. are of course uncertain and the illustrations of relationships should only be viewed as suggestions.

6.2.1 The energy input factor effect

Energy as an input factor plays a fundamental role in the relationship between energy and non-energy commodities. The proposed causal relationship is that energy prices affect the prices of non-energy commodities through the energy related cost of production and transportation (illustrated below in figure 6.1). Mitchell (2008) attributes 25-30 % of the increase in food prices from 2002-2008 to this factor (as well as exchange rate effects). Other authors are careful with specifically quantifying how much this effect may account for, but mention it as being important in the energy/non-energy commodity price link (Baffes 2009, Baffes & Haniotis 2010).

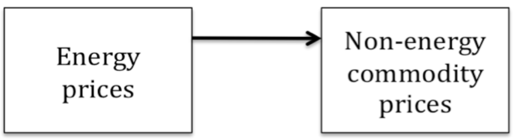

Figure 6.1: The energy input factor effect. *Energy prices affect the prices of non-energy commodities through the energy-related costs of production and transport*

The laws of thermodynamics imply that the relationship illustrated in figure 6.1 must be true in a physical sense. Energy is an input factor for the production of *all* commodities and in principle nothing could be produced without energy. However, in an economics framework energy prices will only affect a commodity if the energy related costs are large enough to have a significant impact on the overall price of the end product. This implies that two aspects of the energy input factor effect must be considered for each commodity; *the energy cost in production and transport* as well as the *price of the end product*. Thus, it is the *relative* and not the *absolute* energy cost of a product that are of importance.

For industrial metals and minerals the role of energy as an input factor may play a considerable role. Mining, melting and processing are energy intensive procedures and since most metals are quite heavy and bulky, transportation may also be of importance. Iron, steel, aluminum and copper are examples of metals with a high absolute energy intensity per unit of output. However, since the end-price of the metals may vary considerable, the relative energy costs are not necessarily high for all products with high absolute energy costs. This is illustrated in table 6.1, which shows an overview of the energy consumption per dollar value for a selected overview of products from US manufacturing. Producing one ton of aluminum requires much more energy than producing one ton of steel or iron. However, aluminum prices are also much higher than steel or iron prices and as a result, energy consumption is lower compared to the end value of the product.

Product	**Energy consumption per dollar value (MJ/USD)**
Cement	59.1
Iron and steel	29.3
Pulp and paper	16.0
Aluminum and alumina	12.9
Chemical manufacturing	9.0
Food manufacturing	2.7

Table 6.1: Energy intensity of US manufacturing in selected sectors, 2002. Source: EPA 2007. Unit conversion by the author. *Note that the table shows energy use in manufacturing. Energy use before harvest (for food), as well as mining, transportation etc. is not included.*

For precious metals such as gold, silver and platinum the relative energy costs are even lower, as the energy related cost of mining, melting and transport are usually negligible compared to the value of the end product. Furthermore, since precious metals often are not consumed in the sense of being “spent”, continuous production is not necessary to the same extent as for many other commodities. This implies that price relationships between energy and precious metals are hard to argue on the basis of energy as an input factor. However, Sari, Hammoudeh & Soytas (2010) argue that one possible “input factor relationship” may arise through power shortages in some countries that are important producers of precious metals, as high energy prices substantially decrease the precious metals production and thus drive the prices up. The most important example of such a country is South Africa (Sari, Hammoudeh & Soytas 2010).

For agricultural commodities, the relative energy input costs may be large enough to play a significant role. Keep in mind that the numbers in table 6.1 do not fully take into account the energy costs of food production, as only the manufacturing process is included and not the whole process of sowing, cultivation, harvest, transport etc. Furthermore, fertilizer plays an important role, but that will be discussed separately in the next section.

An additional factor to consider is that all energy sources do not cost the same and different kinds of production uses different energy sources. The relative cost of energy is not determined by the quantity of physical energy spent in production, but by how much it costs to consume this energy. I will briefly list the energy mix for available and relevant manufacturing sectors to illustrate this, but in-depth analysis of the cost in each sector is beyond the scope of the thesis. The numbers are 2002 US averages for the respective manufacturing sectors and collected from EPA (2007)[30]. In *food manufacturing,* natural gas is the most important energy source, accounting for 52 % of total energy requirements. It is followed by electric energy[31] at 21 % and coal at 17 %. In *iron and steel manufacturing*, coke and natural gas are the most important energy sources, accounting for 36 % and 26 % of total energy requirements respectively. Furthermore, in *aluminum manufacturing* 55 % of the energy consumption is electric and 37 % supplied from natural gas. These numbers only apply to the manufacturing part of the process, so keep in mind that oil also plays a role as an input factor in transportation.

6.2.2 The fertilizer effect

The role of fertilizer is important for the relationship between energy and agricultural commodities. In reality this is a more complex version of the energy input factor effect, but it still warrants its own separate discussion. First of all, it is clear that energy prices play an important role in influencing the price of fertilizers, as natural gas is a major input factor in

[30] I could not find the corresponding figures on a global basis, but the US numbers still suffice to illustrate the issue.

[31] Keep in mind that some electric energy may again be produced from natural gas or coal.

fertilizer production[32]. For the production of nitrogen-based fertilizer, which is the most important plant nutrient, the International Fertilizer Industry Association estimates that the cost of natural gas amounts to more than 70 % of production cost (IFA 2011). Furthermore, energy related transport cost are also important in determining end-prices for fertilizer, and sometimes transport cost may amount to as much as a third of the final cost to end-users (IFA 2011). One reason for this is that nitrogen-based fertilizer production is often located close to natural gas production and far away from markets (some examples of major production sites for fertilizer are Trinidad & Tobago and Qatar) (IFA 2011).

Secondly, fertilizer prices affect the prices of agricultural products, as fertilizer is an important input factor in production. However, the price of agricultural products also plays an important role in determining fertilizer prices. Farmers usually buy fertilizer on credit and repay when they have sold their harvest, therefore the earnings they expect to receive play an important role in determining how much fertilizer they buy (IFA 2011). Prices of agricultural commodities also determine the overall intensity of agriculture, as high prices might lead to the cultivation of less productive land and vice versa, and in the long run this effect will have an impact on overall fertilizer demand. Furthermore, studies indicate that the farmers' expectations about commodity prices (and thus future income) play a larger role in determining demand for fertilizers than fertilizer price itself (IFA 2011). In addition, price developments in fertilizer markets have lagged the developments in agricultural markets in the period 2007-2010, which may indicate that fertilizer prices follow the prices of agricultural commodities (IFA 2011). Thus, it seems reasonable to conclude that although fertilizer prices have some influence on the prices of agricultural commodities, the opposite effect is definitely present and is even likely to be stronger. The price relationship between energy, fertilizer and agricultural commodities is displayed in figure 6.2.

[32] The most common production process for nitrogen-based fertilizer is through the so-called Haber-Bosch process, where natural gas (methane) and nitrogen from the air are converted into ammonia, which may later be converted into ammonium nitrate or urea. The process can also be based on gasified coal, although that is less common.

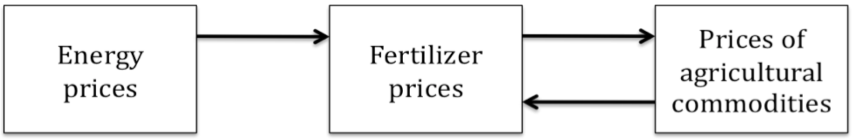

Figure 6.2: The fertilizer effect. *Energy prices and prices of agricultural commodities affect the prices of fertilizer. Fertilizer prices also affect the prices of agricultural commodities, although probably not as strongly.*

6.2.3 Biofuels

It has been argued that biofuels are important in determining the price linkages between energy and food markets (Cashin, McDermott & Scott 1999, Mitchell 2008). The causal relationships between energy commodities, biofuels and agricultural commodities are relatively complex. Energy prices are important in determining the prices of bioethanol and biodiesel, in fact these two products *are* energy commodities[33]. Furthermore, biofuel prices affect the demand for biofuel crops (corn, sugar, oils), which again also are used as food for humans and animals, implying that the food market plays an important role in determining the prices for these agricultural commodities. Moreover, other crops might be grown on the same land as biofuel crops, meaning that there might be an interaction through land use changes and changes in the intensity of production. For example, high prices of biofuel crops might lead to the displacement of soybeans or wheat (Mitchell 2008, World Bank 2009), causing the supply of these commodities to shrink and prices to increase. The same argument applies in the opposite direction.

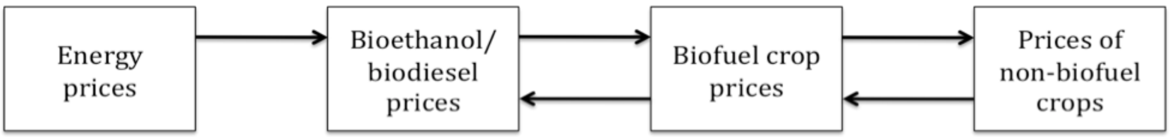

Figure 6.3: Biofuels. *Energy prices affect the prices of bioethanol and biodiesel. These products again interact with the prices of biofuel crops and non-biofuel crops trough land use change and adjustments of cultivation intensity.*

Looking at my own analysis, it was at first very interesting to observe that among the agricultural commodities all three major biofuel crops (corn, sugar, palm oil) were cointegrated with crude oil, while the other agricultural commodities were not. However, before concluding that it is biofuels that cause this apparent long-term price relationship, it is

[33] Some authors even argue that *food is energy* as a catchy explanation to why food and energy markets exhibit price comovement. This phrase is true in the physical sense, but without the presence of a real economic relationship it is not a valid explanation. Humans cannot eat crude oil and cars cannot run on noodles. However, biofuels are the one main area where this phrase does hold some truth.

important to keep in mind that the price series go back to 1982. Biodiesel production was practically non-existent before 2000 and bioethanol production was considerably less important than today (REN21 2010). The biofuel regime is very likely too young to affect a model for the entire period 1982-2010, and other causes such as the input factor effect, fertilizer use or macroeconomic factors could potentially be behind the relationship. However, it is unclear why these factors should significantly affect the biofuel crops of corn, sugar and palm oil, but not the other agricultural products.

Mitchell (2008), examining the period 2002-2008, attributes 70-75 % of the increase in food prices to biofuels. Baffes & Haniotis (2010) are more skeptical to the role of biofuels and write concerning the 2007/08 food price boom that *"the effect of biofuels on food prices has not been as large as originally thought"* (p. 2). Again, as all three major biofuel crops were cointegrated with crude oil in 1982-2010, there might be *other* important fundamental factors driving the long-term price relationship between crude oil and corn, sugar and palm oil. These factors might be present also in newer data and could perhaps erroneously be attributed to the biofuel regime.

Another interesting aspect to consider is that the price relationship between energy and biofuel crops may only be relevant when energy prices exceed certain threshold levels. For example, the World Bank (2009) found that with today's biofuel regime and technology, bioethanol from corn is only profitable to produce at oil prices exceeding USD 50 per barrel. At oil prices higher than USD 50, each percentage point increase in the oil price was found to increase the price of corn with 0.9 %, while there were no significant relationships between the two prices when the oil price was lower than this threshold level (Word Bank 2009).

6.2.4 GDP and macroeconomic factors

Business cycles or macroeconomic factors such as inflation or (dollar) exchange rates are often proposed as causing price movements in commodity markets[34] (Mitchell 2008, Lescaroux 2009, Sari, Hammoudeh & Soytas 2010). These factors may affect both energy and non-energy commodity prices and thus may co-drive the prices of both types of

[34] For structural simplicity and convenience I have chosen to lump these factors together in one section rather than discussion them individually. A separate discussion of business cycles (gdp), exchange rates etc. would perhaps be more orderly.

commodities. However, one must also consider the macroeconomic influence of energy. The oil price is an important macroeconomic indicator that can have substantial influence on financial markets, and energy prices (in particular the price of crude oil) influence the overall level of economic activity and growth on a country basis. Thus, energy prices affect aggregate demand and through that mechanism may have an impact on the price of most commodities (FAO 2002).

Empirically, some evidence in favor of a macroeconomic price relationship can be found. Hannesson (2009) found a positive relationship between growth in energy use and growth in GDP, and a negative relationship between energy use and oil prices for most countries. Furthermore, Stern (2010) found energy use and overall economic growth to be cointegrated variables when controlling for others factors of production (capital, labor). One could of course argue that it is increased affluence that leads to more consumption of energy and not added energy use that is associated with higher GDP. However, Stern (2010) also found energy use to positively Granger cause GDP output, meaning that increases in energy consumption lead increases in GDP. Another interesting finding is that the effect of energy on GDP was found to be much stronger in periods of relative energy scarcity than in periods of energy abundance (Stern 2010). This finding is logical since energy abundance implies that the constraint imposed by energy as a factor of production is less restrictive. Perhaps there are also macroeconomic effects of non-energy commodity prices such as minerals, metals, raw materials etc., but I have chosen not to research this topic due to the scope of the thesis. In addition this influence is likely to be smaller than that of energy and oil prices.

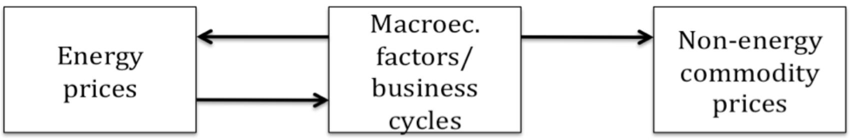

Figure 6.4: Macroeconomic factors. *Macroeconomic factors and business cycles may have an impact on both energy and non-energy commodity prices. Energy prices also affect macroeconomic factors and business cycles.*

Sari, Hammoudeh & Soytas (2010) examined the role of exchange rates closer, and no significant relationships between dollar exchange rates and oil prices were found. However, there were strong long-term and short-term relationships between dollar exchange rates and the prices of precious metals. However, due to the lack of a relationship with energy prices, these findings do not support the idea that exchange rates co-drive energy and precious metals prices (Sari, Hammoudeh & Soytas 2010).

Lescaroux (2009) argues that macroeconomic conditions in commodity markets play a major role and are best controlled for using inventory levels. Applying other variables such as inflation, stock or bond market development or exchange rates is insufficient and will likely lead to finding significant relationships caused by spurious regression. To demonstrate this, Lescaroux (2009) duplicated the original results of Pindyck & Rotemberg (1990), but found that after controlling for shocks to inventory levels there were almost no significant links between unrelated commodities.

6.2.5 Capital protection

Capital protection has been proposed as a possible link between precious metals and energy (Cashin, McDermott & Scott 1999, Baffes 2009, Kagraoka 2011). The proposed theory is that high energy prices are associated with inflationary pressure, slower economic growth and resource scarcity, while precious metals (in particular gold) traditionally has been viewed as a "safe investment" and a hedge against inflation (Cashin, McDermott & Scott 1999, Baffes 2009, Kagraoka 2011). Consequently, high oil prices create investor demand for capital protection, which again increases the demand of gold as an investment object.

Figure 6.5: Capital protection. *Energy prices affect the demand for capital protection, which again has an impact on the prices of precious metals.*

There is empirical evidence in support of precious metals, especially gold, being used for capital protection (see e.g. Sari, Hammoudeh & Soytas 2010. The more uncertain part of this proposed causal relationship is thus whether energy prices significantly affect the demand for capital protection and if so through what mechanisms. I have not been able to find studies investigating this matter. Even though it seems plausible that energy prices may affect the demand for capital protection, the question remains open.

6.2.6 Speculation and commodity asset bubbles

One of the cornerstones of traditional finance has been the efficient market hypothesis (EMH), which states that all publicly available relevant information is reflected in the price of an asset and that prices immediately respond as new information is made public (semi-strong form). Many authors have use terms such as *speculation*, *herd behavior, sunspots*, *asset bubbles* or *excess liquidity* to refer to unexplained price comovement in commodity markets (Pindyck & Rotemberg 1990, Cashin, McDermott & Scott 1999).

In recent years these more or less imprecise terms have been made more stringent through the relatively new field of behavioral finance. Within this field it is theorized that human beings, on the individual level, are susceptible to relying on rules of thumb and psychological biases when estimating outcomes or probabilities. Aggregated to the market level, the sum of this behavior may translate into market anomalies. This implies that the actual prices of assets may deviate substantially from fundamental values, which represents a contradiction to EMH. The most relevant phenomenon within behavioral finance for commodity price comovement is the presence of asset bubbles. They might appear as the prices of several commodities increase in price more or less at the same time and in a self-reinforcing fashion. Conversely, the prices may plummet at the same time when the bubble eventually bursts and liquidity constraints and panic arises.

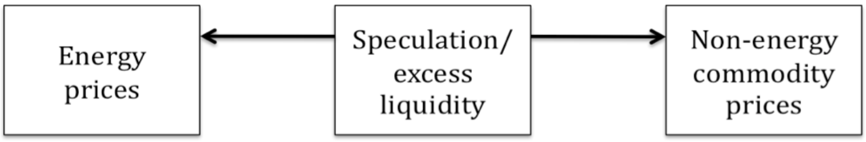

Figure 6.6: Speculation. *Speculation may lead to commodity asset bubbles, affecting the prices of both energy and non-energy commodities.*

Empirically, Cashin, McDermott & Scott (1999) found *"no evidence of irrational trading behavior by participants in world commodity markets"* (p. 9). However, keep in mind that their analytical method has been criticized on a fundamental level by e.g. Lescaroux (2009). Others, such as economic historian Charles P. Kindleberger claims that historically there have been numerous examples of irrational price bubbles, also in commodity markets (Kindleberger 2000).

7. Conclusions

"A conclusion is the place where you got tired of thinking" – Martin H. Fischer

This paper set out to examine how the prices of international energy commodities comove geographically within each market, across energy carries and with non-energy commodities.

Geographically, oil markets have been strongly integrated into one global market up until the recent divergence between Brent Blend and WTI in 2011, while coal and natural gas markets have been less integrated. Although oil markets have had the strongest geographical integration, coal markets are integrated to a greater extent than natural gas markets and some recent empirical evidence indicates that the presence of a single global coal market is likely. Nevertheless, some price rigidity does exist in coal markets, as well as certain isolated areas with their own price behavior. Natural gas markets are divided into at least two geographical price areas consisting of the Americas and Europe/Asia-Pacific, possibly three areas centered on Europe, North America and Asia-Pacific. These findings are logical when taking the transport cost per energy unit into account; oil is cheaper and more convenient than the other two to transport. Furthermore, coal shipping is substantially cheaper than natural gas pipelines or LNG, although transporting coal over land is more expensive. There might also be other factors limiting geographical integration for natural gas and coal, particularly infrastructure and contracting concerns.

In terms of price comovement across energy commodities, empirical evidence indicates that although oil, natural gas and coal are substitutes in many uses both directly and on a system wide basis, it is not correct to consider these three commodities as part of one integrated energy market. However, some price comovement between the three certainly exists, in particular between oil and natural gas, where fairly strong regional integration has been identified in e.g. the US and UK.

The price relationships between energy and non-energy commodities have not been extensively researched. Several of the studies that include empirical testing of these relationships do it indirectly, with a main focus on other topics. Nevertheless, a relatively strong link between energy and agricultural products has been found in several studies (Mitchell 2008, Baffes 2009, Baffes & Haniotis 2010). The link between energy commodities and industrial metals has, to my knowledge, not been directly examined. Two studies found significant and relatively strong price relationships (Pindyck & Rotemberg

1990, Baffes 2009), while Lescaroux (2009) only found a very weak relationship after controlling for macroeconomic factors. For precious metals, several studies indicate a significant relationship with energy (Pindyck & Rotemberg 1990, Cashin, McDermott & Scott 1999, Baffes 2009), however Sari, Hammoudeh & Soytas (2010) found no such relationship.

In my own empirical testing I found relatively strong cointegration relationships between crude oil and sugar, tin, gold and silver in the period 1982-2010. I also found cointegration relationships between crude oil and corn, palm oil and iron ore. However, for iron ore and corn the results were highly sensitive to the selected lag length in the ADF test, while there were some minor problems with the price series for palm oil.

Although both the literature and my own empirical testing indicate that some long-term price relationships between energy and non-energy commodities are present, the type of analysis normally carried out is not well fitted to determine exactly what causes these price relationships. There are many theories and hypotheses, among them the role of energy as an input factor in production and transportation, the fertilizer effect, biofuels, business cycles, exchange rates, inflation, capital protection and speculation/asset bubbles. Any or several of these factors may be behind the price relationships that are indentified. Nevertheless, some highly speculative conclusions about causal relationships may be drawn. The importance of the energy input factor can partially be judged from looking at the energy costs of production and transportation relative to the end price of the output. Energy as an input factor is likely to play an important role for commodities such as steel, iron, aluminum and perhaps also agricultural commodities, both directly and through fertilizer. For precious metals the energy input factor is likely to play a smaller, perhaps insignificant, role due to the high end-price of the commodities and the fact that they are often not "spent" in the same way as other commodities. Business cycles (GDP growth) also seem to play an important role for most commodities and some researches even consider this to be by far the most important causal factor. Furthermore, judging from empirical results, (dollar) exchange rates seem to play a relatively insignificant role. In the case of precious metals, the role of capital protection is also of some importance, as it has been quite firmly established that precious metals are indeed used as capital protection. However, whether the prices of energy products have an impact on the demand for capital protection remains a question to be addressed more thoroughly. Again, this depends on the relationships between energy prices and factors such as business cycles and inflation. The last causal factor discussed is speculation and asset bubbles, which is a controversial topic. This factor is at the core of the whole discussion about whether commodity prices comove "excessively" or not. The question of speculation and asset bubbles also remains open, as there have been several articles and books supporting both sides of the argument. However, recent developments within the field of behavioral finance do present the behavioral fundamentals that might be behind market anomalies of this kind.

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Chapter quotes

Chapter 2: *"Books serve to show a man that those original thoughts of his aren't very new at all."* - This quote is attributed to the American president Abraham Lincoln.

Chapter 3: *"(...) the tale of the drunk and her dog offers a reminder to applied statisticians that the cointegration relationship is not merely a statistical convenience with no behavioral content."* - Teachers within statistics have often used the example of a drunken man to describe a random walk; his movements are random and only depends on his current position. Furthermore, a random walk with a (negative) drift can be illustrated as a drunken man walking in a sloping field. Again his movements are random, but over time they are likely to follow the downward slope of the field. In a 1994 article in the *American Statistician,* Michael P. Murray illustrates cointegration and error correction as a drunken woman walking her puppy. Both move randomly compared to any fixed object and may deviate substantially from each other in the short term. However, in the long term they are likely to stay within the proximity of each other.

Chapter 4: *"When the going gets tough, the tough get empirical"* - Attributed to the American journalist Jon Carroll.

Chapter 5: *"The master economist [...] must understand symbols and speak in words."* This quotation is from the essay "Alfred Marshall, 1842-1924" by the famous British economist John Maynard Keynes. It can be found on page 322 in the *Economic Journal of the Royal Economic Society*, vol. 34 (135), September 1924.

Chapter 6: *"Everything is related to everything else"* – According to the US biologist Barry Commoner this is the first law of ecology. The quote can be found in the book *The closing Circle* from 1971.

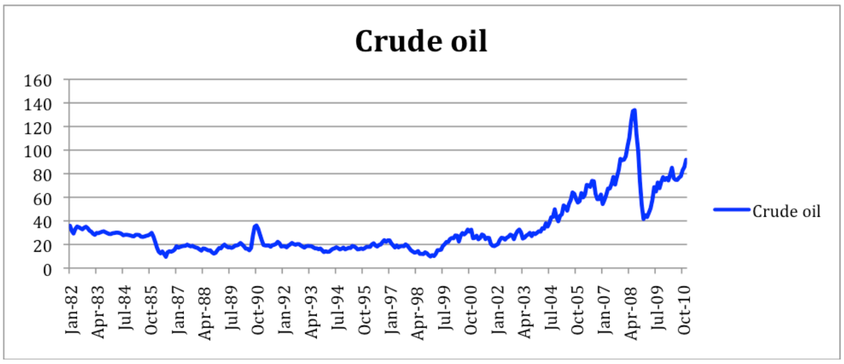
Conclusion: *"A conclusion is the place where you got tired of thinking"* – This quotation is from the American/German physician Martin Henry Fischer.

Appendix

A. Full description of price series

A description of the characteristics of the price series from the Indexmundi database follows, as well as graphs showing how they have developed from 1982:1 to 2010:12.

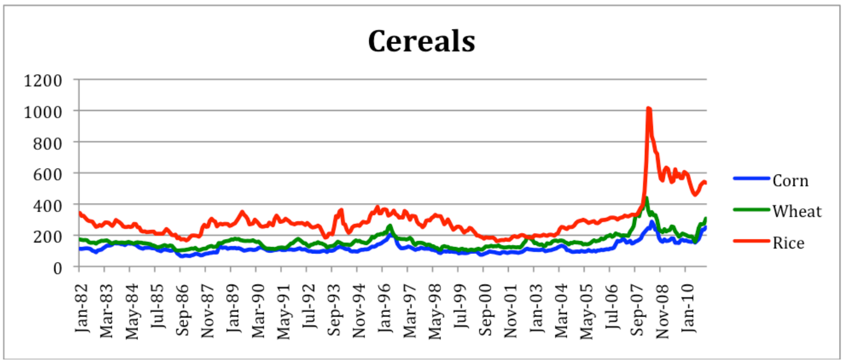
Crude oil: Dated Brent, North Sea, USD/barrel.



Corn: U.S. No. 2 Yellow, FOB Gulf of Mexico, U.S. price, USD/metric ton.

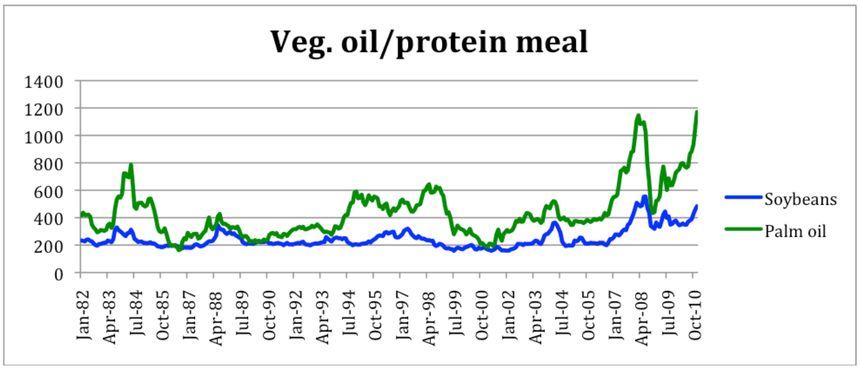
Wheat: No.1 Hard Red Winter, ordinary protein, FOB Gulf of Mexico, USD/metric ton

Rice: 5 percent broken milled white rice, Thailand nominal price quote. USD/metric ton.

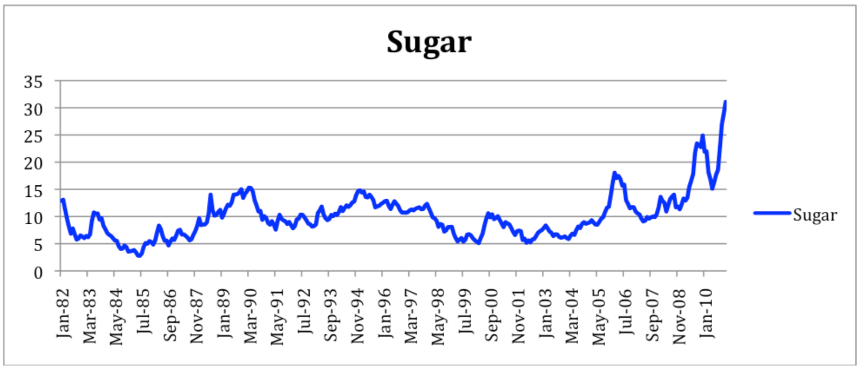


Soybeans: U.S. No. 2 Yellow, FOB Gulf of Mexico, U.S. price, USD/metric ton

Palm oil: Malaysia Palm Oil Futures (first contract forward) 4-5 percent FFA, USD/metric ton



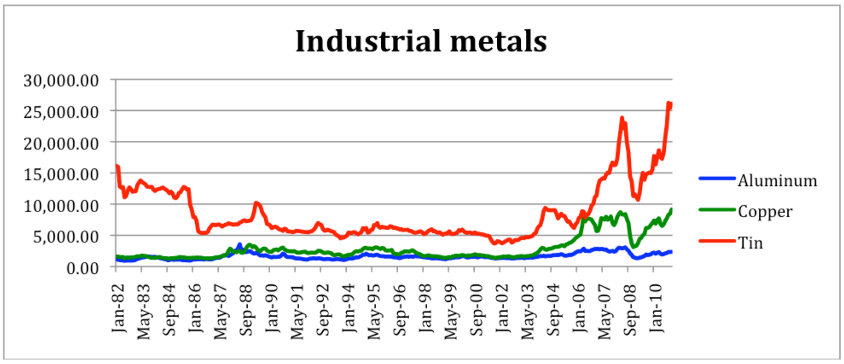
Sugar: Free Market, Coffee Sugar and Cocoa Exchange (CSCE) contract no. 11 nearest future position, US cents per Pound



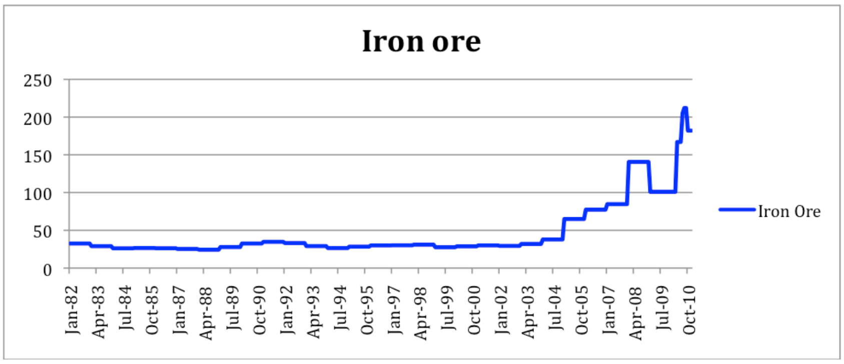
Aluminum: 99.5% minimum purity, LME spot price, CIF UK port, USD/metric ton

Copper: Grade A cathode, LME spot price, CIF European port, USD/metric ton

Tin: Standard grade, LME spot price, USD/metric ton

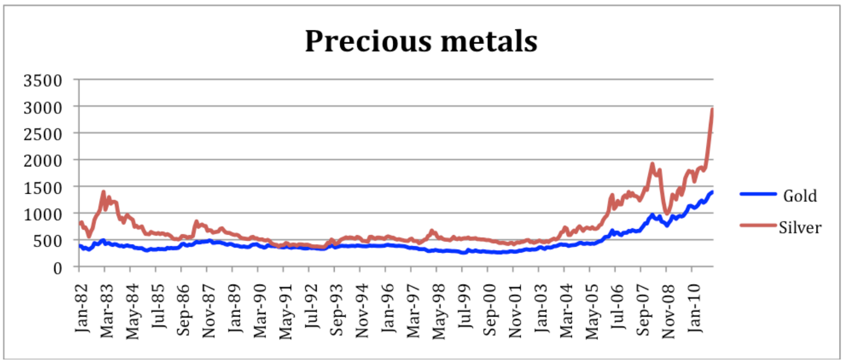


Iron Ore: 67.55% iron content, fine, contract price to Europe, FOB Ponta da Madeira, US cents/Dry Metric Ton



Gold: UK, 99.5% fine, London afternoon fixing, average of daily rates, USD/Troy Ounce

Silver: Handy & Harman, 99.9% grade refined, New York, US cent/Troy Ounce



Note that silver is quoted in US cents and gold in USD.

B. ADF table for the short price series (2000:1-2010:12)

VARIABLE	*LEVEL VALUES*		*FIRST DIFFERENCES*	
	Constant +trend	*Constant*	*Constant +trend*	*Constant*
Crude oil	***-3.95****	***-2.25***	***-4.25*****	***-4.18*****
Corn	*-3.41*	*-1.50*	*-6.36***	*-5.92***
Wheat	*-2.85*	*-1.59*	*-4.36***	*-4.23***
Rice	*-2.95*	*-1.65*	*5.34***	*-5.23***
Soybeans	*-2.79*	*-1.20*	*-4.98***	*-4.84***
Sugar	*-1.05*	*1.01*	*-5.91***	*5.29***
Palm oil	*-3.27*	*-0.95*	*-4.94***	*-4.53***
Aluminum	*-2.05*	*-1.69*	*-5.08***	*-4.90***
Copper	***-3.03***	***-1.09***	***-3.27***	***-3.21****
Iron Ore	***-3.46****	***-0.77***	***-7.95*****	***-7.59*****
Tin	***-3.51****	***-0.94***	***-5.31*****	***-5.09*****
Gold	*-0.97*	*1.48*	*-8.75***	*-8.30***
Silver	*-1.18*	*1.12*	*-5.53***	*-5.32***

Table 5.2: ADF test results for the period after 2000 (2000:1 to 2010:12).
H_0: Non-stationary against H_A: Stationary
Critical values with constant and trend: 5 % = -3.44 and 1 % = -4.03
Critical values with a constant: 5 % = -2.88 and 1 % = -3.48
* Significance at 5 % level, ** Significance at 1 % level.

With a constant and a trend, the null hypothesis of non-stationarity for crude oil, iron ore and tin is rejected at the 5 % level. It is thus uncertain whether these price series are non-stationary and they should not be used in a cointegration test. For copper, the first differences appear to be non-stationary when a trend and constant is included, but not with only a constant. It is not sufficient for a cointegration analysis that variables are non-stationary, they must also be integrated of the same level and therefore copper also could not be included in a cointegration test. The H_0 of non-stationarity was rejected at the 1 % level for all other commodities.