The Coal Market

Structure and Price Dynamics - A Cointegration Approach

Bachelor Thesis
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Abstract

This thesis analyzes the structure and price dynamics of the global steam coal market. A qualitative analysis of the coal market leads to the conclusion that coal is one of the most important fossil fuels and its importance is expected to grow further. The main part of this thesis uses time series econometrics to describe the structure and price dynamics of the global coal market. It tests whether three regional coal prices are cointegrated and estimates an error correction model to model their short-term dynamics. Here both the Engle-Granger two step approach and the Johansen test for cointegration are used. These lead to the conclusion that the global coal market can be considered to be integrated in the long term, but that the European and Pacific coal markets are more closely connected in the short-term than the American market with either of them. The same techniques are used to analyze the relationship between coal, gas and oil prices. A long-term equilibrium is found between coal and gas prices, in the short term however the prices seem to be only loosely connected. Not even a long-term equilibrium was found to describe the relationship between coal and oil.

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List of Abbreviations

BT Billion Tons

BTU British Thermal Units

CCGT Combined Cycle Gas Turbines

C.I.F. Cost, Insurance and Freight

CCS Carbon Capture and Storage

CO2 Carbon Dioxide

DF Dickey-Fuller

ECM Error Correction Model

EU European Union

F.O.B. Free on Board

GT Giga Tons

IEA International Energy Agency

IGCC Integrated Gasification Combined Cycle

KW Kilo Watt

MT Million Tons

MTOE Million Tons of Oil Equivalent

OECD Organisation for Economic Co-operation and Development

OLS Ordinary Least Squares

PPP Purchasing Power Parity

UK United Kingdom

US United States

VECM Vector Error Correction Model

1 Introduction

Today coal is a truly global commodity: it is not only the most important source of power for electricity generation but also the largest contributor to climate change. Furthermore it is found widely in 70 countries all over the world. Even though the use of coal is often criticized for causing more pollution than alternative fuels, most experts expect coal to retain its importance if not increase it in the years to come. On the other hand its heterogeneity and high transportation costs make it a relatively local commodity, less than a fifth of worldwide coal trade is international. Thus the question arises whether there is one worldwide market for this commodity or rather a number of distinct regional coal markets. Furthermore the question of the relationship of coal and other fossil fuels is interesting. Knowing how closely connected the markets are for coal, oil and gas would help extensively in explaining the dynamics governing the coal market.
This thesis aims to analyze the world market for coal by putting a special emphasis on its structure and price dynamics. The main questions this thesis attempts to answer are:

- Is there one integrated worldwide coal market?
- How do regional coal markets influence each other, i.e. how do price movements in one location transmit to other regions?
- Can coal, oil and gas be considered to be part of one integrated market for primary energy sources?
- How do the prices of these commodities influence each other?

In order to discuss these questions this thesis begins in chapter two with a brief introduction to coal as a resource, its properties, reserves, main uses, production and the implications of the climate change debate. While this chapter does not give an answer to the main question of this thesis, it gives a necessary introduction to the coal market. The third chapter of this thesis characterizes the worldwide coal market by describing the role of coal, its production and consumption in different regions. It thus paints a qualitative outline of the structure and dynamics of the world coal market. Chapter four and the core of this thesis then use time series econometrics, namely cointegration analysis and error correction models, to address the questions concerning the structure and dynamics of the coal market by applying a more structured empirical approach. In order to do this the theory behind both cointegration analysis and error correction models will be presented. After explaining why these techniques are useful to answer the questions posed above they will be used on price data of coal in three different regions, in order to test for global market integration and the short-term dynamics between these regions. Secondly the techniques will be used on price data of coal, natural gas and crude oil in order to test whether there is a long-term equilibrium between their prices. This would support the hypothesis of one integrated energy source market, after this the short-term dynamics between the prices of these resources will be looked at.

2 Coal, the Energy Source of Yesterday?

Today coal is only rarely discussed when talking about electricity generation: It has been in use for a relatively long time, seems antiquated and most of the coal fired power plants in the western world are already long in use and seem to be a remnant of a past long gone. On the other hand coal is still the most import fuel for electricity generation and it seems unlikely that this will change in the near future. On the contrary due to the economic rise of China and other emerging economies whose power generation is mainly based on coal, most experts expect a revival of coal and a strong growth in its consumption and trade. This chapter gives a short introduction to coal, its properties, use, production and the impact of the climate change debate on the use of coal.

2.1 Coal and its Use

According to Miller (2005, p. 1) coal is a "chemically and physically heterogeneous, combustible, sedimentary rock consisting of both organic and inorganic material." The organic components of coal are mainly "carbon, hydrogen and oxygen, with lesser amounts of sulfur and nitrogen." Inorganic components are only relatively minor in coal and "vary from several percentage points down to parts per billion of the coal." Coal is generally found in so called seams that stem from "accumulation of vegetation that has undergone physical and chemical changes." This process includes the decaying of the vegetation and other processes through which biomass is converted to coal. This coalification also describes the metamorphism that coal undergoes as it transforms from peat to anthracite. As this process and the original vegetation as feedstock are always unique the resulting coal is a rather heterogeneous resource (Miller, 2005, p. 2). Because different kinds of coal have to be used in different manners coal is commonly classified by further attributes which will be presented in the next section.

2.1.1 Classification of Coal

For industrial use coal is mainly described by three characteristics which are essential for its proper use and will be presented briefly in this paragraph. They among others determine the energy content and physical appearance of coal which are essential to it's use as a combustion fuel (Miller, 2005, p. 4).
The Rank of Coal: A measure of "the extent of metamorphism the coal has undergone". According to this coal can be sorted in four categories: lignite, sub-bituminous coal, bituminous coal and anthracite. Lignite is the lowliest ranking coal while anthracite is the highest ranked coal which has thus undergone the longest process of coalification. A high rank of coal also implies a high carbon content, and thus a high energetic value (Miller, 2005, p. 6).
The Coal Type: Coal is composed of microscopic constituents called macerals. These can be divided in three groups which are characterized by their chemical composition, appearance and optical properties. They are called vitrinite, exinite and intertinite and are different due to specific components of the plants from which they were formed (Miller, 2005, p. 7).
The Grade of Coal: The grade of coal is a measure of quality which is defined by the amount of minerals present in the coal. The grade of coal can also be measured via the sulfur content, the quantity of trace elements or ash fusion temperatures (Miller, 2005, p. 8).
Of these three attributes the rank of coal is arguably the most important for its potential use and thus value. The distinction between the four ranks of coal are also presented in figure 1.
The difference between steam and coking coal depicted in the figure 1 mainly stems from the use of the coal where coking coal is defined as "hard coal with a quality that allows the production of coke suitable to support a blast furnace charge" and steam coal "as all hard coal which is not coking coal" (International Energy Agency, 2007). Steam coal is primarily used for energy production and accounts for the by far biggest part of the coal market. Thus this thesis is only analyzing the structure and price dynamics of the steam coal market. Unless mentioned otherwise only steam coal will be the topic of the rest of this thesis.

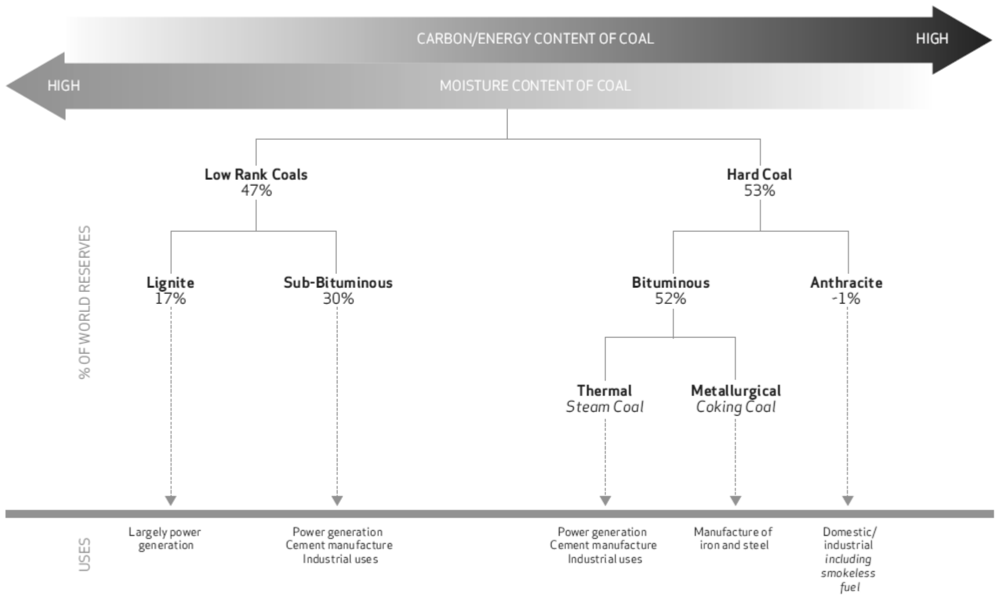

Figure 1: Types of Coal - *Source: World Coal Institute(2005)*

2.1.2 Coal Reserves

Compared to other fossil primary energy resources like oil, coal is relatively abundant. According to the Survey of Energy Resources by the World Energy Council (2007) there are around 850 billion tons of coal which are judged "currently recoverable". At the current rate of production these resources would last around 137 years, a much higher figure than the equivalents for gas and oil, which are represented in figure 2 (Energy Information Administration, 2009a). Furthermore the estimated reserves are expected to grow further by the discovery of new reserves or by advances in mining techniques which would allow more efficient mining (World Coal Institute, 2005).
The number depicted in figure 2 only represent coal which is under current conditions deemed economically recoverable, thus the total amount of resources is significantly higher. A recent reduction of almost 7 percent of the appraisal of the recoverable coal reserves was for example not due to a change in acknowledged resources which are quite well known but just in the estimation what amount of the reserves are deemed recoverable (Energy Information Administration, 2009a). Concerning the world coal reserves it is important to state that coal is found in almost all regions of the world and in over 70 countries many of which can be judged geopolitically less unstable than the main oil and gas producers. In general it can be stated that coal reserves are far less concentrated in some regions than oil and gas. While 41% of the gas reserves and 63%

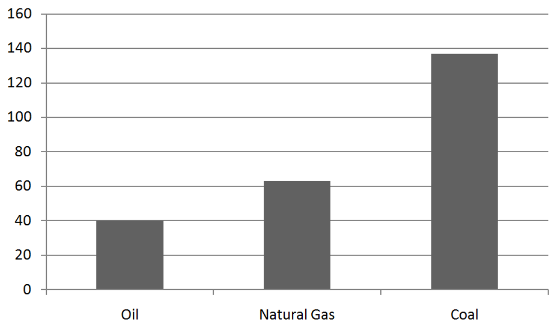

Figure 2: Reserve to Production Ratios in years - *Source: Energy Information Administration (2009a)*

of worldwide oil reserves are located in the Middle East there is no significant part of coal reserves found in this region (World Coal Institute, 2005). It can be concluded that coal is relatively abundant, there will be enough reserves for coal consumption in the foreseeable future. In chapter 3 the proven reserves of coal will be presented in more detail and especially regional differences and the locations of the biggest coal reserves will be discussed.

2.1.3 Coal Mining

The techniques used to mine coal are mainly influenced by the geological attributes of the site. If coal is found in relatively little depth, surface mining can be possible, if the coal is situated deeper in the ground underground mining is necessary to extract the coal from its seams. In the following paragraph these two techniques will be presented concisely.

Underground mining can be further separated in two main techniques: room-and-pillar and long wall mining. The former is a method with which rooms are cut into the coal seams which leave pillars to support the roofs of the rooms. While these can sometimes be recovered they mostly remain buried underground. This makes this method rather inefficient, often leaving up to 40% of the coal unrecoverable. Longwall mining can help to recover up to 75% of the coal deposits by "mechanical shearers" that mine long walls of coal as one piece. This technique is more efficient than room-and-pillar mining but requires more capital investments and takes longer to install than the equipment for room-and-pillar mining. Machinery required for this method often costs less than $5 million instead of around $50 million for long wall mining machinery (World Coal Institute, 2005, p. 7).

Surface Mining, also called opencut or opencast mining, is much more efficient than the methods described above and normally helps to exploit more than 90%

of the coal reserves. Surface mines often cover an area of several square kilometers and thus require large pieces of equipment. Some time and substantial capital investments are therefore necessary to use this technique. Furthermore the large areas required to mine often pose problems, as these may conflict with near residents or habitats of animals (World Coal Institute, 2005, p.8).
According to the World Coal Institute (2009) underground mining accounts for 60% of worldwide coal production. In some important coal producing countries however surface mining plays a more important role: It accounts for 80% of the coal production in Australia and for 67% of coal production in the United States. As presented above this technique is more efficient than underground mining and thus could help to explain the prominent role of these two countries in the coal market, presented in more detail in the next chapter.

2.1.4 Coal as a Fuel for Electricity Generation

According to the International Energy Agency (2009) the vast majority of coal is used for power generation: 69% of coal demand in 2002 stemmed from power generation, this share is expected to increase to 79% until 2030 (World Coal Institute, 2005). Coal based power generation represented a share of 42% of worldwide electricity generation in 2006 (Energy Information Administration, 2009b). According to forecasts of the Energy Information Administration (2009b) this share is expected to stay stable until 2030. The percentage of coal used in electricity generation varies widely in different countries. While some countries such as Poland, South Africa and China produce the by far biggest share of their electricity through coal, other countries use far less coal for their electricity production. Relying heavily on nuclear power, France for example only produces 5% of its electricity with coal plants (World Coal Institute, 2005). Figure 3 presents the 2002 share of coal in the electricity generation of the countries whose electricity production is most dependent on coal.

A detailed description of the process how coal is used to generate power would be beyond the scope of this thesis. Nevertheless the most important facts about the main methods used to produce electricity with coal will be mentioned hereafter. This is especially important in order to better understand the relationship between coal and other primary energy fuels which is also addressed in the quantitative part of this thesis.
The most common form of electricity generation with coal is called “pulverized-coal combustion” (PCC) and accounts for over 90% of worldwide coal fired capacity (World Coal Institute, 2005). PCC thus accounts for around 40% of all electricity production worldwide. It involves the following steps: First the

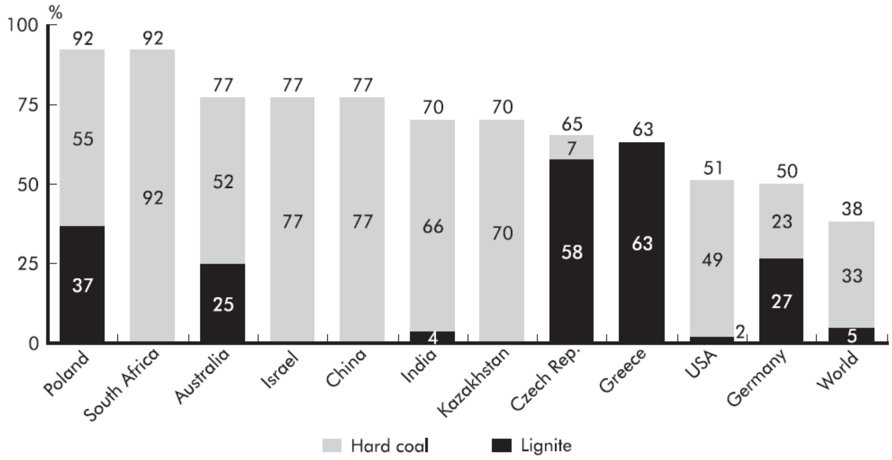

Figure 3: Share of Coal in Power Generation in selected Countries (2002) - *Source: Coal Industry Advisory Board (2005)*

coal is dried and heated. At temperatures of around 500 degrees Celsius the second step, called devolatilisation, is commencing. It involves the fuel being transformed to volatiles and char. The third step is commonly called combustion of volatiles. It involves the volatiles reacting with oxygen. It leads to the fourth step the combustion of chars which contributes the majority of heat to the process. A more detailed presentation of the PCC process can be found in the publication "Fundamentals of coal combustion" presented on the "Coal Online" website from the International Energy Agency. Other methods to burn coal use fixed or fluidized beds of coal to burn the coal and produce heat. The heat from the PCC or of the other methods is then used in steam turbines to create electricity (Carpenter et al, 2007).
Today new state of the art coal power plants have energy efficiencies of above 40%, thus transforming more than 40% of the heating value of the coal to electricity, but the worldwide average is far below and closer to 30%. This is especially true for developing countries where less efficient plants are often constructed due to their smaller capital costs (Sims et al, 2003). Figure 4 shows average efficiencies of coal power plants in different country groups and their CO2 emissions which will be discussed in a section below. Here a big difference between developed and the most important developing coal consuming countries becomes obvious. China and especially India are a long way back in terms of efficient coal power generation. Thus there is the potential to either drastically increase output of coal fired power plants or reduce their coal consumption.

New developments such as supercritical coal plants, which burn coal at higher

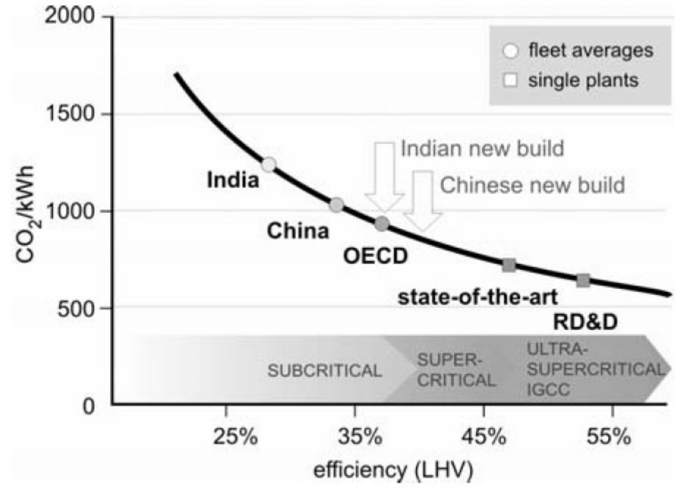

Figure 4: Power Plant Performance - *Source: World Energy Council (2007)*

temperatures, would even allow coal plants with efficiencies up to 50%. Another approach are "integrated gasification combined cycle" (IGCC) systems in which coal is first transformed into a gas and then used similarly as gas in gas power plants. Current IGCC systems have efficiencies of up to 50% but net efficiencies of up to 56% are expected to be realized in the future. In 2005 there were around 160 IGCC plants in use (World Coal Institute, 2005).
Due to the relative low price of coal it is principally used to generate the base load of power. Thus coal plants efficiency is a bigger concern than their flexibility. Other sources of base load power are mainly nuclear power plants while gas power plants are usually more flexible but also more expensive and thus mainly used for power peaks (Cordaro, 2008). Coal can therefore not be considered as a direct substitute for the other two fossil fuels, as petrol is rarely used for power generation and gas is mainly used for power generation at power peaks.

2.1.5 Other Uses of Coal

While this thesis is covering the market for steam coal, coal especially in the form of coking coal is also used for other purposes than electricity generation. The second most important use is the use of coking coal to make steel, 64% of steel produced worldwide is from blast furnaces which use coking coal. In these coke, which is made of coking coal, is used to heat and reduce iron ore. This and other less important industrial uses represented 16% of coal demand in 2002. According to estimates of the Energy Information Administration (2009b) this value is predicted to shrink to 12% until 2030. Other uses of coal include coal liquefaction, where coal is transformed into a liquid fuel, the cement industry where it is used to heat the ingredients of cement and other industries where it is often used as a source of carbon (World Coal Institute, 2005).

2.2 Coal and Climate Change

Today, when talking about energy supply most of the time the main topic of the discussion is climate change. This is arguably one of the most important phenomena facing mankind and electricity generation is one of the biggest contributors to it. Climate change is not a subject of this thesis. However, as the climate change debate will probably have a big impact on the coal market, it has to be considered in order to get a complete picture of the market for coal. First the greenhouse gas emissions by coal and other sources will be discussed and compared. After this, technologies which make coal combustion more efficient, thus having the potential to reduce CO2 emissions, as well as carbon capture and storage technologies will be presented briefly.

2.2.1 CO2 Emissions by Coal

Since 2006 CO2 emissions from coal account for the highest share of global greenhouse gas emissions originating from fossil fuels. Its share rose from 39% of emissions in 1990 to 42% in 2006 overtaking emissions from liquid fossil fuels, mainly oil.

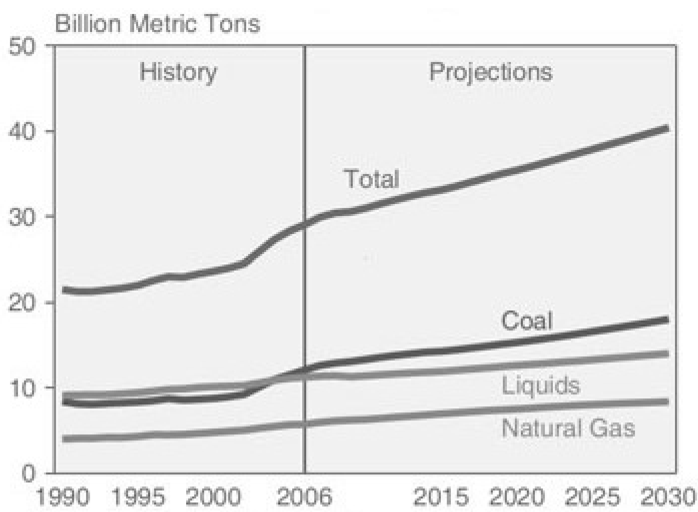

Figure 5: World Energy related CO2 Emissions by Fuel Type, history and projections - *Source: Energy Information Administration (2009c)*

The trend that coal is increasingly responsible for greenhouse gas emissions is expected to continue. In 2030 the Energy Information Administration expects coal's share of CO2 emissions to be 45% of total emissions from fossil fuels and roughly 40% higher than today's amount of emissions. Figure 5 depicts the developments of the CO2 emissions of the three main fossil fuels since 1990 and the projections for their respective future output until 2030 by the Energy Information Administration(2009c). The main causes for the expectation of a rising share of coal related CO2 emission are the increasing importance of emerging market economies, mainly China and India, which heavily depend on coal plants for electricity generation. This is also illustrated by figure 6 which depicts the CO2 emissions of coal combustion in OECD, thus most of the developed countries and non OECD countries and their projections until 2030 according to calculations of Energy Information Administration (2009c). The fact that from 2000 onwards almost the entire growth of CO2 emissions is caused by countries which are not members of the OECD has to be emphasized in this context.

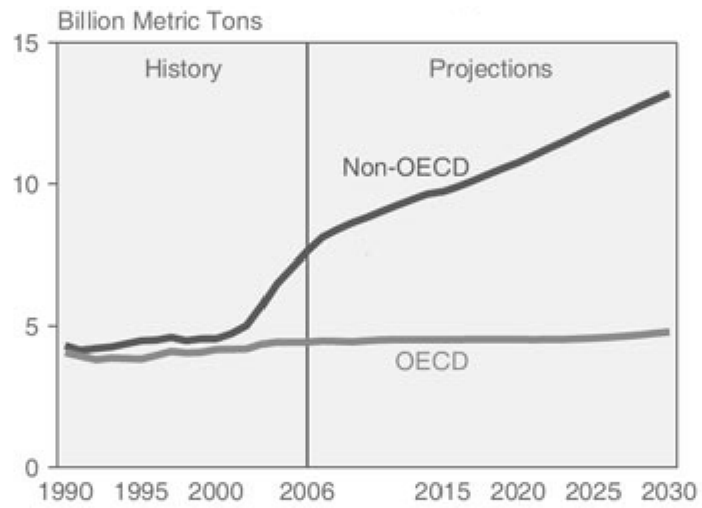

Figure 6: Greenhouse Gas Emissions from Coal Combustion, history and projections - *Source: Energy Information Administration (2009b)*

The prominent role of coal in the discussion about CO2 emissions is not only due to the fact that coal is the most important fuel for electricity generation but also because producing electricity from coal is much more carbon intensive than other means of production. Figure 7 represents the CO2 emissions per kWH of produced electricity of coal, other fuels and techniques to generate electricity.

Burning coal to generate electricity produces almost twice as much CO2 emis-

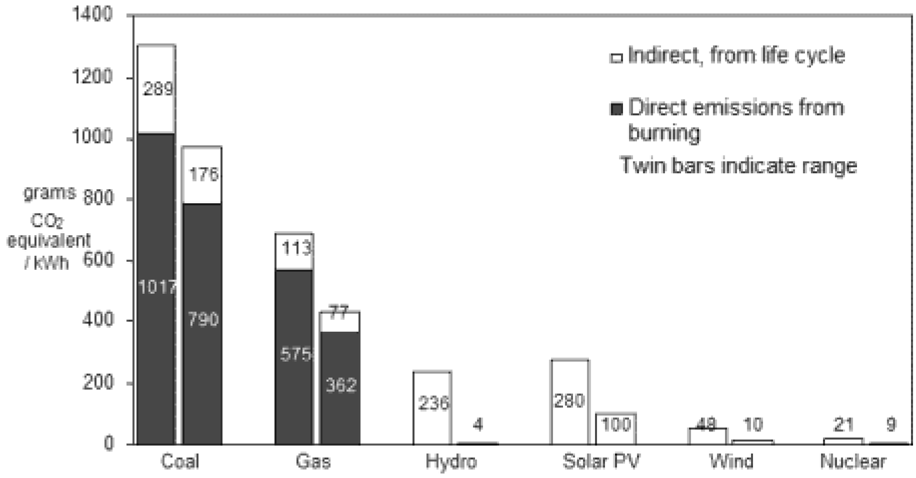

Figure 7: Greenhouse Gas Emissions from Electricity Production - *Source: World Nuclear Association (2009)*

sions than the same process using gas power plants. This is mainly due to three reasons: Gas power plants, especially combined cycle gas turbines (CCGT), produce at much higher efficiency levels than coal power plants. They are thus able to use the heat of the gas combustion better than coal plants. Furthermore gas has a higher heating value which means that a certain amount of gas can produce more heat than the same amount of coal. Additionally natural gas consists of less carbon than coal (Sims et al., 2003). Other energy sources such as nuclear power and regenerative sources of energy produce even less CO2 per unit of electricity generated.

2.2.2 Cleaner Coal Use

Even if the use of other fuels for electricity generation is not feasible, large reductions of the CO2 emissions are possible when combustion efficiencies of coal fired power plants are improved. Figure 4 shows how an improved efficiency of coal plants reduces the emitted CO2 per unit of energy produced. A 1% point increase in today's level of efficiency would lead to a 2-3 percentage point decrease in emissions. As presented above the technologies for a significant increase in efficiency are available and improved technology pushing the efficiency even further are expected to be on the market in the near future. Up to now relatively high costs of these technologies have hindered their advances: According to the World Energy Council (2007) typical IGCC plants have investment costs of US$ 1,500 / kW compared with only US$ 750/kW for conventional systems and US$ 1,000/kW for advanced conventional plants. The World Energy Council (2007) argues however that if costs of emissions of CO2 and other pollutants are taken into account IGCC would already be competitive. While these efficiency oriented policies can lead to reductions of up to 25% of coal related emissions of greenhouse gases they still leave coal less carbon efficient than other fuels.

Another approach which is still further off but which is currently widely debated is "Carbon Capture Storage" (CCS). CCS technology allows the capture of carbon dioxide from the exhaust stream of coal combustion. Once the CO2 emissions are captured it is necessary to store them safely and permanently as to avoid them entering to the atmosphere. Today so called geological storage is considered to be the most feasible way to store CO2 for a long time. Carbon dioxide is injected into the subsurface of the earth. Especially depleted gas and oil reservoirs are considered for this purpose. They are reckoned to have a capacity of 800 and 126 gt of CO2 respectively. "Deep saline water-saturated reservoir rocks" are also considered to store captured carbon dioxide. Estimates of their capacity range from 400 to 10,000 Gt of CO2 (World Coal Institute, 2005). The capture technology is well known, as it has been used for years to produce CO2 for other industries. The technologies for safe CO2 storage are still in development. The first demonstration CCS plants are now under construction and are scheduled to open at the beginning of the coming decade. Eurocoal (2008) expects the first economically viable CCS plants to hit the market after 2020. The viability of this technology however, is not yet proven and largely depends on further developments of the technology, costs of CO2 emissions, coal and other fuels. Its main problems are its costs and the reduction of the efficiency of the power plants as a part of their energy production must be used to transport the carbon dioxide to its destination.

2.3 Coal - an Energy Source with a Future!

The answer to the question in the title of this chapter has to be a categorical "no". Coal still is and can be expected to remain one of the predominant energy sources for the decades to come. Even though the debate about climate change poses a threat to this role of coal it cannot be expected to diminish the use of coal drastically in the next decades. This is mainly due to the widespread use of coal, which is especially intense in fast growing, power hungry economies such as China and India. Furthermore the relative abundance and widespread coal reserves are a major advantage of coal compared to other fossil fuels such as oil and natural gas.

This chapter has underlined the importance of coal for electricity production worldwide. It has shown that even though the role of coal is affected by the discussion about climate change its role in power generation cannot be suppressed in the near future. Furthermore it became clear that coal is mainly used for other purposes than petrol and gas. For gas, often used for power peaks in electricity production, this might however be different in the long-term, as big moves in the price of either gas or coal might lead to substitutions between these energy sources. The hypotheses to be tested in chapter 4 are therefore: In the short-term the market for primary energy fuels is not integrated. In the long-run however there is a closer connection between gas and coal than between oil and coal. The second part of chapter 4 addresses these questions by using time series econometrics in order to test these hypotheses.

3 The Global Market for Coal

In 2007 international coal trade accounted for only 16% of global coal consumption. The Energy Information Administration (2009b) expects a decrease to only 14% in 2030 as most growth of coal consumption is expected to take place in countries which are relying mainly on domestic coal. Figure 8 shows the amount of coal produced and consumed in the most important coal producing and consuming countries in million tons of oil equivalent. The figure explains the relatively low importance of international trade in coal. The by far two biggest coal producing countries, China and the United States are also the biggest coal consumers. They mainly consume their domestic coal. Only Australia, Indonesia and to a lesser extent Columbia and South Africa produce far more than they consume. Primarily Japan, South Korea, Taiwan and some western European countries are their trade counterparts by consuming significantly more coal than they produce.

The bulk of international trade therefore takes place between Australia, Indonesia, Colombia and South Africa as main exporters and the previously mentioned east Asian countries and to some degree western Europe as importers. If only steam coal is considered, Indonesia overtakes Australia as the worlds biggest exporter. This is also visible in figure 9 presenting international steam coal trade flows in 2008.

As mentioned above, coal reserves are relatively abundant, with a reserve to production ratio far above one hundred years. These ratios and reserves however differ largely between the main coal producing countries. Figure 10 presents the remaining coal reserves of the main coal producers as a bar chart with the years these reserves would last at current production rates as numbers above the bars. Here, significant differences are obvious: While some big producers,

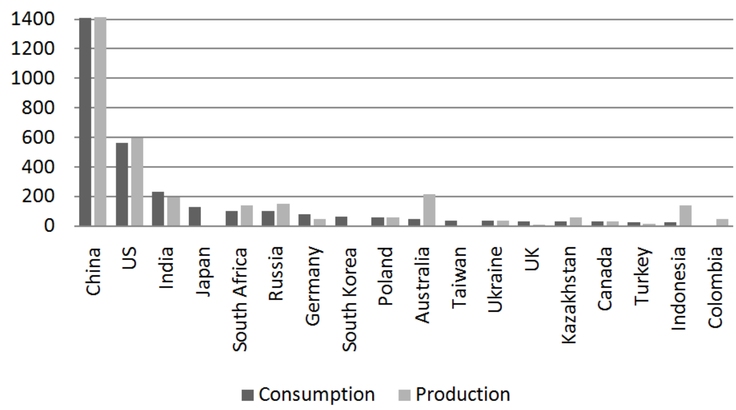

Figure 8: Coal Consumption and Production per Country in 2008 in Mtoe - *Source: Europe's Energy Portal (2009)*

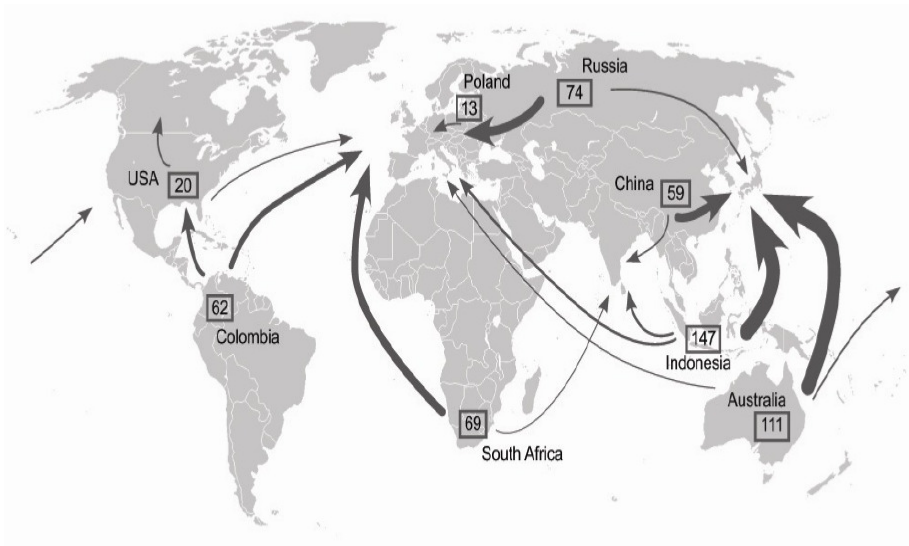

Figure 9: International Steam Coal Trade flows in 2008 (Mt) - *Source: International Energy Agency (2009)*

such as the United States, still have plenty reserves others, including China, have far smaller reserves which might be too small to hold up production in the long term. This could then lead to more international trade in steam coal in the long-term, as big producers with a low reserves to production ratio would have to substitute domestic coal with imports. The next chapter will discuss these differences in further detail on a regional basis.

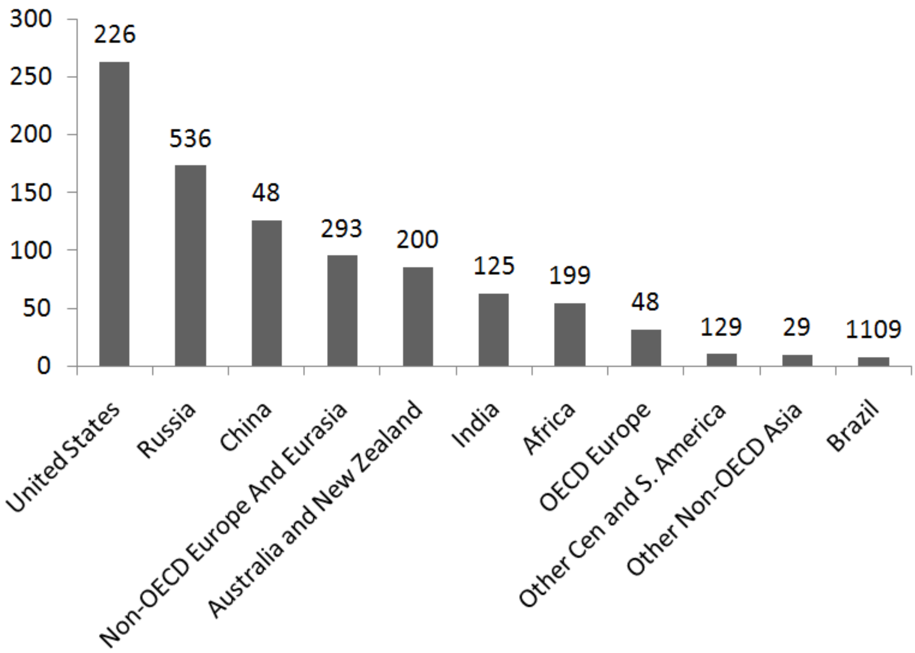

Figure 10: Recoverable Coal Reserves (bars, in bt) per Country and the Reserves to Production Ratios (numbers above bars, in years) - *Source: Energy Information Administration (2009b)*

3.1 The Major Coal Producing and Consuming Regions

In order to better understand the structure and price dynamics of the global coal market it is important to know details about the regions influencing the coal market. Some act mainly as exporters or importers while others primarily produce coal for their domestic use. This chapter presents the main facts about coal production and use in China and the United States, the two biggest coal producers and consumers. Hereafter the main facts about Europe as well as Japan, South Korea and Taiwan the biggest coal importers are presented. Australia and Indonesia as the biggest exporters of coal are presented at the end of this section. The most important facts about coal transportation are discussed before coming to a conclusion and developing hypotheses about the structure and price dynamics of the coal market which will be tested and further developed in the main section of this thesis. The main question these hypotheses will try to help to answer is whether or not there is a worldwide market for coal or if the global coal market has to be looked at as different markets in different world regions.

3.1.1 China

As figure 8 shows, China is by far the largest producer and consumer of coal. It produces and consumes more than one third of world coal production. Even though the Chinese electricity demand today is largely met by coal fired power plants, see Figure 3, more than half of the coal used in China is used in non-electricity sectors, the biggest part in the industrial sector. This is mainly due to the fact that China is the leading producer for pig iron and steel (Energy Information Administration, 2009b). The use of coal for power generation however is projected to increase significantly. Thus the biggest part of Chinese coal is projected to be used in the energy sector, overtaking the industrial use of coal which is still expected play a very significant part. This is also illustrated in Figure 11 below which depicts the use of coal for different sectors in China in 2006 and in Projections of the Energy Information Administration (2009b) up to 2030. These projections indiciate that not only the distribution of coal consumption in different sectors are expected to change significantly but also that the total amount of coal consumption will increase drastically. This is mainly due to the electricity sector which is expected to more than double its consumption.

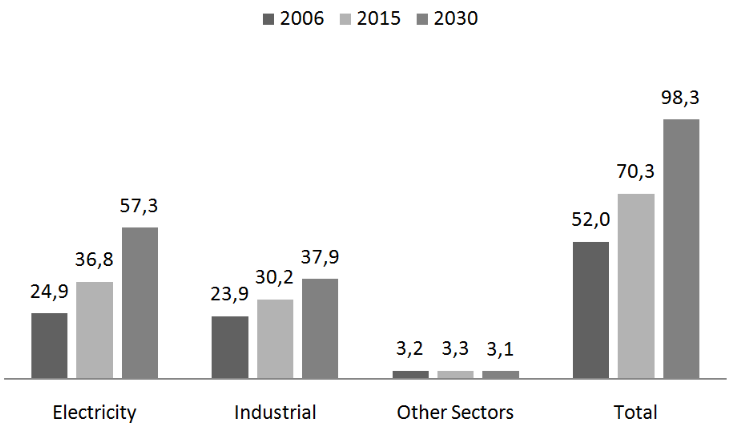

Figure 11: Coal Consumption in China by Sector, 2006 and Projections for 2015 and 2030 in Quadrillion Btu - *Source: Energy Information Administration (2009)*

While China today is the by far largest producer of coal its reserves are only the third biggest, after he United States and Russia. Thus China has a lower reserves-to-production ratio, of only 48 years, than most other big coal producer. Even though the Energy Information Administration (2009b) expects China to produce most of its coal domestically, it also sees China to switch from being a net exporter of coal to become a small net importer in the near future.

3.1.2 United States

The United States are not only the second largest coal producer in the world but they also have the highest amount of proved recoverable resources of coal. The share of coal in electricity generation was 49% in 2006 and is expected to decrease slightly to 47% in 2030 (Energy Information Administration, 2009b). In 2008 92% of coal used in the United States was accounted for by power generation with the remainder almost exclusively used in the industrial sector (Energy Information Administration, 2009b). Two thirds of the coal produced in the United States is mined by surface mining, making the coal production in the US relatively cheap (World Coal Institute, 2005). In the United States coal reserves are relatively abundant and would last for another 226 years at current production rates. Figure 12 shows the main regions of coal mining and their coal output in the year 2008.

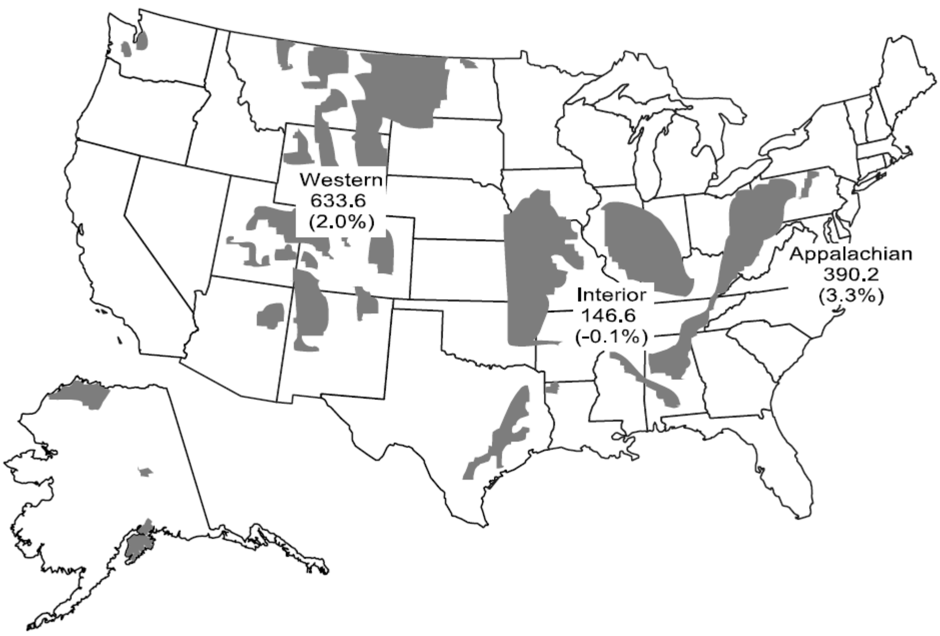

Figure 12: US Coal Production in 2008 by Coal Producing Region, in million short tons and percentage change from 2007 - *Source: Energy Information Administration (2009a)*

Wyoming alone contributed 40% percent to the coal production in 2008. West

Virginia, Pennsylvania and Kentucky were the next biggest coal producers accounting for another 30% of the coal production of the US. In terms of international trade of coal the United States are rather unimportant, importing and exporting rather insignificant amounts from Colombia and to Europe.

3.1.3 Europe

Today, Europe is the third biggest consumer of coal in the world. In 2007 18% of the EU-27 primary energy supply came from coal, representing a 29% part of the electricity generation in the European Union. This number however masks big differences between European countries: In Poland over 90% of electricity is generated by coal while Sweden's electricity supply is virtually non reliant on coal (Eurocoal, 2008). Furthermore Europe is almost the only market for coal where lignite and other low ranking coal play an important part in the electricity production, see also Figure 3. In 2006 it accounted for 24% of total coal consumption, measured on a BTU thus an energy level, in OECD Europe (Energy Information Administration, 2009b).

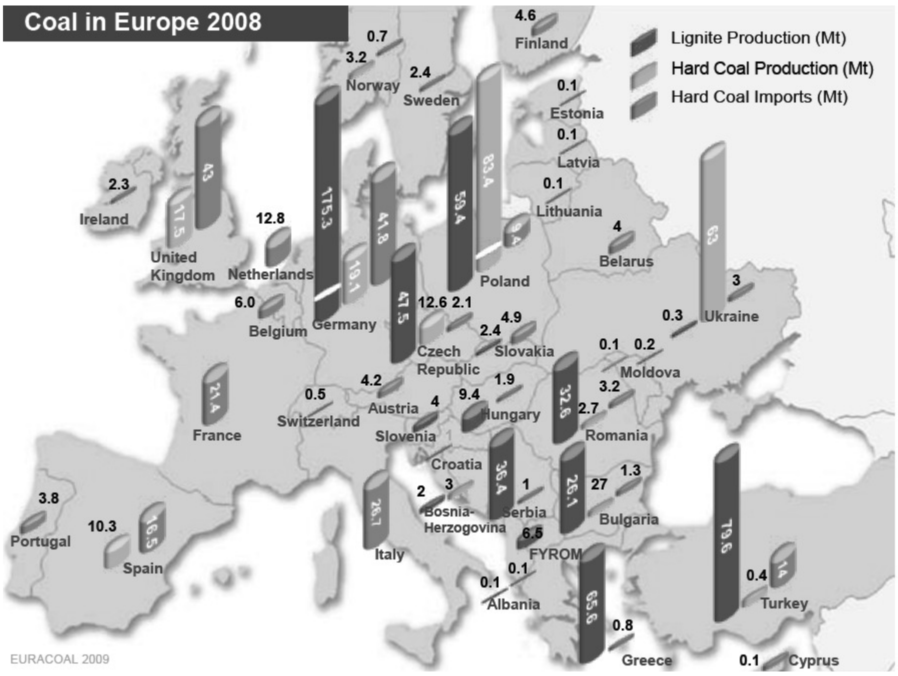

Figure 13: Coal Production and Imports in Europe - *Source: Eurocoal(2009)*

Germany and Poland are the leading producers of coal in Europe, additionally

200 mt of its 455 mt yearly consumption are imported to Europe. Figure 13 provides more data about the coal production and imports in all European countries. This figure especially underlines the heterogeneity of the European coal market: Some countries such as Germany and the United Kingdom are responsible for the largest part of European imports, while others virtually do not use any coal. Even though the share of coal imports is expected to increase to 63% in 2030 the coal industry in Europe is far less dependent on imports than the oil and gas industry whose import dependence lied at 82% and 56% respectively in 2005. The main sources of coal for European imports are South Africa, Colombia and the Ukraine (Eurocoal, 2008). While electricity consumption is expected to grow steadily coal consumption is expected to be flat until 2030, according to the Energy Information Administration (2009b). This is mainly due to government policies to reduce greenhouse gas emissions and discourage the use of fossil fuels, especially those with a high carbon content.

3.1.4 Japan, Taiwan and South Korea

In 2008 Japan, Taiwan and South Korea were the three biggest importers of steam coal with imports of 128, 76 and 60 mt respectively. This accounted for 35% of worldwide steam coal imports (World Coal Institute, 2009b). As all of these countries have no significant domestic production of coal, they rely fully on imported steam coal which comes in large parts from Australia and Indonesia. In Korea about 40% of electricity is generated by coal combustion, with 25% this share is lower in Japan. In Taiwan just over half of electricity is generated with coal as fuel (Energy Information Administration, 2009b).

3.1.5 Australia

Australia has been the biggest exporter of coal since 1984, of its coal exports however more than half was coking coal rendering Australia only the second biggest exporter of steam coal (World Energy Council, 2007). For coking coal it is however predominant, supplying 70% of Asia's demand for coking coal imports and 61% of worldwide coking coal imports. Concerning steam coal, Australia's role is less dominant: it supplies 29% of Asia steam coal imports, which account for more than 90% of Australian steam coal exports. Australia provides a global share of 19% of international steam coal exports (Energy Information Administration, 2009b). It has the fourth biggest recoverable reserves of coal and with a reserves-to-production ratio of 200 years it is well placed to keep its role as the world's most important exporter of coal. This is also supported by the projections of the Energy Information Administration (2009b) which expects Australia to overtake Indonesia as the world's biggest exporter of steam coal.

Big investments in its export capacity and transport infrastructure have been done recently. One third of its coal production is used for local consumption of which the biggest part is used for power generation. This represented 85% of the hard coal consumption in 2004 and accounted for more than three quarters of its electricity generation (World Energy Council, 2007).

3.1.6 Indonesia

Indonesia is the largest exporter of steam coal accounting for 30% of worldwide steam coal trade and 42% of steam coal exports to Asia. 82% of its steam coal exports went to Asian importers with the rest being mainly shipped to European destinations. Its coking coal exports are however relatively small, accounting for less than 10% of worldwide coking coal trade. This leaves Indonesia as the second biggest exporter of coal in general (Energy Information Administration, 2009b). Its recoverable coal reserves are less than 10% of the coal reserves deemed recoverable in Australia. They are however some of “the cleanest coal in the world” as they have low ash and sulphur contents. In 2005 Indonesia exported 71% of its total coal output and consumed two thirds of the domestically used coal for power generation (World Energy Council, 2007).

3.2 Transportation

Today about 90% of international coal trade is seaborne. There is often a distinction between the Atlantic market, mainly with Germany, the UK and Spain and the Pacific market which consists mainly of Japan, South Korea and Taiwan. The former trade mainly with Colombia and South Africa as exporters and the latter import most of their coal from Australia and Indonesia. This is mainly due to relatively high transportation costs of coal which can, according to the HMS Bergbau AG (2009), account for up to 80% or 90% of the coal price at its destination. This is much higher than for other primary fuels, the transportation costs of oil, for example, only account for a single digit share of the end user oil price.

3.3 Hypotheses about the Structure of the Coal Market

This chapter outlined the basic structure and dynamics of the global coal market by describing the most important regions for this market and the role coal plays in their economies. The most important facts about the global coal markets presented in the chapter were: Most coal trade is domestic. While China and the United States are the biggest domestic coal markets their influence on the world market is limited as they have neither significant imports nor exports.

The most important players in the international coal market are Indonesia and Australia as big exporters to the pacific region, Japan, South Korea and Taiwan in particular. Europe also plays an important but smaller role as the second biggest import market. Coal exported to Europe comes however from other sources, mainly South Africa, Colombia and the Ukraine. Therefore the markets in Europe and Japan seem to be not too closely connected with each other or the markets in China and the United States. The hypotheses that follow from this line of argument are therefore: The regional coal markets in the Pacific region, Europe and the United States cannot be considered to be closely integrated. The markets for coal in the pacific region and Europe can be expected to be in a closer connection than with markets in the United States, as both rely more heavily on imports than the United States. In the long run they could however have a closer relationship as main trade routes could change. This is limited by relatively high costs of transportation for coal. The next chapter of this thesis tests these hypotheses by using econometric methods. Because there are only limited data sources, Japanese import prices are used as a proxy for prices in the pacific market.

4 Cointegration and Error Correction Models

In order to be able to better analyze the worldwide market for steam coal this paper uses a relatively new field of time series econometrics, namely cointegration and error correction models, which has been developed in the last 20 to 30 years. Cointegration helps to describe the dynamics of two or more non stationary time series which are in a relationship in which they cannot drift too far from a long term equilibrium relationship. Furthermore the dynamics of cointegrated variables can be modeled according to an error correction model which describes their movements and reactions to deviations from this equilibrium and therefore can help to explain rather short-term dynamics of the variables (Wooldridge, 2006). This chapter summarizes the most important facts about cointegration and error correction models before presenting the common test methods for cointegration. Then a short paragraph describes why cointegration analysis is useful in order to describe market structures and delineate markets. After reviewing the relevant literature that uses cointegration analysis and error correction models to describe the world market for coal, this thesis uses the mechanisms presented before to test worldwide cointegration of coal prices in order to determine if there exists an integrated market for steam coal. After this, error correction models are used to describe the short-term dynamics between these prices. Furthermore it is tested if the price for coal and other primary energy fuels are cointegrated as to support the idea of one single market for primary energy fuels. Additionally the dynamics between these prices are analyzed by error correction models.

4.1 Cointegration

Considering two or more time series variables and the relationship between them, time series econometrics usually requires them to be stationary to provide useful results. This is necessary as, for example, a regression between two non stationary variables might be spurious. A spurious regression between two variables can lead to false conclusions as it often produces seemingly significant results and a relatively high R^2 even though the variables are not dependent of each other. If however two or more non stationary variables are cointegrated, meaning that a linear combination of them is stationary, such a regression leads to usable results and may help to explain the long and short-term dynamics governing them (Brooks, 2008). This thesis uses the theory of cointegration in order to explain the dynamics governing the coal price.
In order to explain the concept of cointegration a model of cointegration of only two $I(1)$, thus non stationary, time series is used. The concept however is basically the same if more than two time series are considered.
If Y_t and X_t are two $I(1)$ processes there might exist a b such that

$$u = Y_t - bX_t \tag{1}$$

is an $I(0)$, thus stationary, process. If such a factor exists Y_t and X_t are said to be cointegrated with the cointegration vector b (Wooldridge, 2006, p. 647).

The more general definition by Engle and Granger (1987) is: "The components of the vector x_t are said to be *cointegrated of order d,b*, denoted $x_t \sim CI(d, b)$, if (i) all components of x_t are $I(d)$; (ii) there exists a vector $\alpha(\neq 0)$so that $z_t = \alpha' x_t \sim I(d-b), b > 0$. the vector α is called the cointegrated vector."

A concept similar to cointegration as it is known today was first mentioned in a famous paper by Davidson, Hendry, Srba and Yeo (1978) in which they argued that a model is needed to explain time series which are in a long-term equilibrium and cannot drift too far away from it. The term cointegration was coined by Granger in 1983 when he formulated the phenomenon that "nonstationary processes can have linear combinations that are stationary" (Johansen, 2009, pp. 671). He also described the relationship between error correction models (ECM) and cointegration. Engle and Granger (1987) were also the first who introduced a statistical test to check for cointegration of two or more variables: the so called Engle-Granger two step approach which will be described in further detail below.

According to Hamilton (1994, pp. 573) “Cointegration means that although many developments can cause permanent changes in the individual elements of Y_t and X_t, there is some long-term equilibrium relation tying the individual components together”. The example of purchasing power parity (PPP) is often used to illustrate cointegration, the theory states that goods should cost the same, apart from transport costs etc., in different countries but that temporary deviations from this equilibrium are possible. Therefore PPP prices in two, or more countries, should be cointegrated which can be shown empirically to be true.

4.2 Market Delineation using Cointegration Analysis

In this thesis cointegration analysis is mainly used in order to check if there is one worldwide coal market and to describe its short and long-term dynamics. Market delineation using cointegration is based on the definition of a market through a common price and mainly based on the theory developed in the paper ”The Extent of the Market” by Stigler and Sherwin (1985). They argue that ”the test of a market that we shall employ is the similarity of price movements within the market” (Stigler & Sherwin, 1985, p. 557). Thus a test for cointegration offers a test for what Stigler and Sherwin consider being the prerequisite of a market. Asche et al. (1997) show in an example using prices of European high-quality seafood that cointegration analysis is really useful to test market integration by applying cointegration analysis and a demand analysis which requires more data on the same products and come to the same conclusion. McNew and Fackler (1997) however use a spatial equilibrium model to test whether or not market integration and thus the law of one price really leads to cointegrated prices. They then argue that the saying ”correlation does not imply causation” should be modified to ”cointegration does not imply integration” (McNew & Fackler, 1997, p. 204). They claim that cointegration analysis alone is not yet evidence enough to claim whether or not markets are integrated. While this criticism has to be taken seriously and cointegration alone is not enough to prove market integration it would be unwise to dismiss the concept of cointegration to test for market integration as it is unwise to dismiss linear OLS regressions just because their results might be only significant due to correlation and not causation. Cointegration can at least be a good indication that markets are integrated but must be supported by other evidence. As presented below cointegration is also used by other papers trying to describe the coal (Li, 2007, p. 4) or other resource markets.

4.3 Error Correction Models

When two or more variables are cointegrated they can be expressed in an error correction model. The most basic error correction model for two variables cointegrated with the following cointegration equation

$$Z_t = Y_t - bX_t \tag{2}$$

can be expressed as

$$\Delta Y_t = \beta_0 \Delta X_{t-1} - \Phi(Y_{t-1} - \beta X_{t-1}) + \epsilon_t \tag{3}$$

or replacing the term representing the deviation from the equilibrium $(Y_t - \beta X_t)$ with Z_t :

$$\Delta Y_t = \beta_0 \Delta X_{t-1} - \Phi Z_{t-1} + \epsilon_t \tag{4}$$

If the cointegration parameter b is known all terms in the equation are $I(0)$ and thus can be estimated by a standard OLS. This also holds true when the cointegration parameter is estimated using OLS. Then estimators for the parameters of the cointegration equation are super consistent and thus lead to consistent estimations of the error correction parameters (Verbeek, 2008, pp. 330). More complex error correction models can include more lag terms of the first differences of Y_t and X_t but principally work in the same way as the equations above. In order to describe the relationship between the cointegrated variables Φ is of special importance. It determines how much of the deviation from the equilibrium is reduced in the following period and thus helps to determine how fast deviations from the equilibrium disappear and therefore, in case of market integration, how fast arbitrage is used to diminish price differences. Furthermore the parameters of the error correction model might help to describe possible asymmetries in the short-term dynamics of the cointegrated variables. It might for example be possible that one of the variables, in our case prices, is a price leader and the other rather follows. Generally speaking the estimates for β_0 can be describing short-term responses to outside shocks etc. while Φ is describing the process back towards an equilibrium which can be rather fast or slow, depending on the size of Φ.

If more than two variables are cointegrated it is common to express their relationship using an vector error-correction model (VECM) which can be seen as a generalization of the error correction model presented in equation 3. Usually it is specified as follows (Brooks, 2008, p. 350)

$$\Delta y_t = \Pi y_{t-k} + \Gamma_1 y_{t-1} + \Gamma_2 y_{t-2} + ... + \Gamma_{k-1} \Delta y_{t-(k-1)} + u_t \tag{5}$$

While this model is used for the Johansen test for cointegration the error correction models used later to describe the dynamics of coal prices are only bivariate.

Thus the VECM will not be used for the price data on coal and not presented in further detail.

4.4 Tests for Cointegration

Following the argumentation in chapter 4.2 it is thus necessary or at least helpful to know whether the coal prices at different locations are cointegrated in order to have evidence for or against a worldwide coal market integration. To test this, however, it is not enough to perform a standard OLS regression as its results can be spurious. There are several formal testing procedures for cointegration of which two will be used in this thesis.

The first formal testing procedure to test for cointegration was introduced by Engle and Granger in 1987. This procedure however has some problems which will be described below. Therefore other test mechanisms were developed and discussed in the following years. In order to check whether or not the global coal prices are indeed cointegrated this thesis uses the Engle-Granger approach as well as the Johansen test for cointegration. Both tests will be presented in a concise manner before using them on the price data.

4.4.1 The Engle-Granger Two Step Approach

In their 1987 paper Engle and Granger presented a two step testing method to check whether two or more time series are cointegrated. They mainly discuss time series which are integrated of the order of 1 which is enough for the analysis in this thesis. The Engle-Granger two step approach is a residual based test, this means it is necessary to estimate, if not obvious, the cointegration relationship. Then the residual of this relationship, one could say the deviations of a potential equilibrium, are tested for stationarity. If they are stationary the time series can said to be cointegrated.

Before estimating the cointegration equation, however, it is necessary to test whether the variables are of an order of $I(1)$ or higher, a prerequisite to be cointegrated. The standard way to test this is a Dickey-Fuller test. This test has the null hypothesis of a unit root and the alternative of no unit root, thus stationarity of the time series. Details concerning this or other tests can be found in basic econometrics text books such as Wooldrige (2006). If the test does not reject a unit root for the time series but rejects the H_0 for first differences of the time series they can be assumed to be $I(1)$ and can thus be tested for cointegration. Having verified these conditions the next step is to estimate, if the parameters are not obvious, the cointegration regression, which can or cannot include a constant:

$$Y_t = bX_t + c + u_t \tag{6}$$

This can be done by a simple OLS which produces, according to Hamilton (1994), a super consistent estimator of the parameters of the cointegration relationship. These parameters, however, are non-normally distributed. Therefore it is not possible to use them for hypothesis testing (Brooks, 2008, pp. 341). Only its residuals are used for the next step. Furthermore it needs to be said that when the variables turn out not to be cointegrated, the estimates for the parameters are not usable as the regression might have been spurious. In the next step the residuals u_t are tested for stationarity. This can also be done with the Dickey-Fuller test presented above. It is however necessary to adapt the critical values of the test because it is used on residuals of an OLS estimation. The equation is estimated using OLS thus the parameters are chosen to minimize the squared residuals, making the residuals as stationary as possible. Therefore the normal critical values might lead to wrong results as they would too often indicate that a variable is stationary. To address this, higher critical values have to be used to reject the H_0 of unit roots. These were first presented in the 1987 paper of Engle and Granger and further developed in years after and can be found in most text books covering cointegration for example in Brooks (2008).

The second step of the test is the estimation of the error correction model governing the relationship between the two variables and is rather straight forward. As the estimators of cointegration equation are super consistent its residuals can be used to estimate the error correction model using standard OLS and produce consistent normally distributed estimates for the parameters. It is also possible to include one or more lagged terms of the first differences of the variables than in equation 4 in order to produce a better fitting model. As the estimates are consistent and normally distributed they can be used for hypothesis testing and conclusions about the dynamics of the variables can be drawn.

While this approach to test for cointegration has the benefit of being relatively straightforward and simple to understand it has some clear disadvantages. The first is that the test is sensitive to the specification of the cointegration equation, its results can differ depending on which variable is used as explanatory. In most cases it is however not clear which variable should be used for this thus the test could produce conflicting results and may have to be used in both directions. Another problem already mentioned above is that the estimates of the cointegration equation are non-normally distributed. Therefore no hypothesis testing with them is possible. Furthermore this approach cannot test if there are more than one cointegration vector, which is only possible with three or more possibly cointegrated variables. Additionally the test can lack power if the sample is rather small and thus might not reject the null hypothesis of no cointegration even if the variables are cointegrated (Brooks, 2008, pp. 340).

4.4.2 The Johansen Test for Cointegration

In the years following the first publications about cointegration these problems were addressed by other, more complex, testing procedures of which the Johansen test for cointegration is probably the most widely used. It is therefore also used in this paper to confirm the findings that will be made using the two step Engle-Granger approach.

To explain the Johansen Test for cointegration it is necessary to write the error-correction model governing the relationship of N cointegrated variables as a vector error correction model (VECM) of the form:

$$\Delta y_t = \Pi y_{t-k} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + ... + \Gamma_{k-1} \Delta y_{t-(k-1)} + u_t \tag{7}$$

with y_t representing a $Nx1$ vector of the data. As a complete coverage of the mathematical aspects of the Johansen Approach would be too mathematically involved for this thesis only its main concept and the important facts for its usage will be covered. The Johansen test for cointegration is based on a maximum likelihood estimation of the equation above. The test itself centers on the analysis of Π. To estimate the system it is first necessary to decide on the number of lag terms included in the system. This can be done for example by the Schwarz' Bayesian Information Criterion (Brooks, 2008, p. 350). As all terms that represent differences of Y_t are $I(0)$, remember the time series have to be $I(1)$ thus first differences are $I(0)$, it can be shown that Π is not of full rank thus can be rewritten as $\alpha\beta'$ where β is a matrix of the cointegration vectors. These vectors can be "interpreted as a long-term coefficient matrix, since in equilibrium, all the Δy_{t-i} will be zero, and setting the error terms, u_t to their expected value of zero will leave $\Pi y_{t-k} = 0$." (Brooks, 2008, p. 350) Therefore the rank of Π is equal to the number of cointegration vectors of the system. In order to determine if the system is cointegrated it is thus only necessary to know the rank of Π which is equal to the amount of its eigenvalues different from zero. To test this the estimated eigenvalues are put in descending order and then used in one of two different test statistics. It will be tested if they are significantly different from zero. These test statistics are transformations of the eigenvalues and are called λ_{trace} statistic or λ_{max} statistic. Basically both test statistics test the H_0 that the number of cointegration vectors is smaller or equal, in case of the λ_{trace} statistics or equal in case of the λ_{max} statistic against the hypothesis that the number of cointegration vectors is bigger than r. As both test statistics are non normally distributed special critical values have to be used which were produced by Johansen and Juselius (1990). These critical values as well as the test and its mathematical background are presented in more detail in textbooks as Maddala & Kim (1998). Once the number of cointegration vectors and thus the rank of

Π is known they can be used to determine if the variables are cointegrated or not.

4.5 Literature Review Cointegration Analysis in the Coal Market

There are several other papers that use cointegration analysis and an error correction model to determine if and if so how much the global market for steam coal is integrated. All of them use the theory of the law of one price and thus the approach offered by Stigler and Sherwin presented above to determine the relationship between the regional coal markets. They argue that only if the prices of coal are cointegrated there is an integrated market for it.

Warell (2006) uses the cointegration technique to check whether the geographical distinct coal markets in Europe and Asia are part of "a single economic market for internationally traded coal" (Warell, 2006, p. 7). To do this she examines data from the International Energy Agency on coal import C.I.F. prices from 1980 to 2000. For coking coal she finds that the prices are cointegrated and uses an error correction model of the form:

$$\Delta p_{E,t} = b_E \Delta p_{E,t-1} + b_J \Delta p_{J,t-1} + \delta EC_{t-1} \tag{8}$$

She estimates that the change in the European price is influenced by a change in the Japanese price from the previous period by an amount of 0.41 times the Japanese price change and that the error correction parameter is -0.38. Looking at price changes in Japan none of the coefficients is significant. Therefore she states European prices are influenced by Japanese prices but not vice versa. This might be due to the fact that "coking coal prices in Japan normally are settled before prices in Europe" (Warell, 2006, p. 16). Regarding steam coal Warrel finds that the prices in Japan and Europe are also cointegrated. But she argues that short-term responses rather run at opposite direction than in the coking coal market as it is rather the European price that influences the Japanese price. She notes however that "short run responses to price changes are lower for steam coal than for coking coal" (Warell, 2006, p. 17). In order to test if the market integration increased over time Warell splits the period into two 10 year periods. While she finds that the prices of the first period are cointegrated according to a Dickey-Fuller test she finds no evidence of cointegration in the second period. The same is true when using not the price data from the IEA but spot prices provided by MCIS in Europe and Taipower in the Asian market (Warell, 2006, p. 21). She argues however that even though the markets for steam coal are not proven to be cointegrated in the 1990's the integration is stronger as "when analyzing market integration over time indicate that the long-term price change in one region, due to a one percent increase in the other region, is stronger in the 1990's" (Warell, 2006, p. 22).

In a 2007 paper Raymond Li from the Macquarie University, Australia, also tries to establish whether there is a single economic market for the international steam coal industry. Additionally, he tries to describe the "degree of steam coal market integration over time." Rather than using import price data at the main import destinations he uses F.O.B. prices from the main exporters, namely Australia, China, Columbia, Indonesia Poland and South Africa. He uses prices from 1995 to 2007 and thus covers a more recent period than Warell (2006). Also using the technique of cointegration to prove that the global market for coal is one integrated economic market he uses South Africa as an anchor for this analysis as he sees it "as the link between the Pacific and Atlantic regions" (Li, 2007, p. 15). He finds evidence for cointegration for all countries but Indonesia at a 5% significance level and none for Indonesia even at a 10% significance level. In order to test if this cointegration changes over time he uses a recursive estimation of the cointegration parameters. Here he finds that the Colombian price is only cointegrated after 2003 and the price of the other countries only by 2004. Furthermore Li uses a Kalman Filter and a Philips-Sul convergence test which come to the same conclusion as his recursive estimation in showing that all countries, but Indonesia, are cointegrated. Only the Phillips-Sul test shows that Indonesia would be integrated with South Africa, Li explains this by the fact that the Philips-Sul test "allow for transitional divergence" (Li, 2007, p. 25) and thus Indonesia's non integration might just be transitional.

Zaklan et. al (2009) also discuss worldwide integration of the steam coal market. Relying on weekly data from December 2001 to August 2009 they also use the cointegration technique to test for market integration in the global market for steam coal. They accept their first hypothesis that worldwide steam coal prices are integrated. Secondly they test the role of oil prices for the transportation cost of coal but reject the hypothesis of an "integration coal and oil markets in the U.S." (Zaklan et. al 2009, p. 14). In the second part of their paper they try to describe the extent of market integration of the world wide steam coal market and suggest that "the evidence mostly favors the hypothesis of global integration of the steam coal market, but we find signs that integration is not yet complete" (Zaklan et. al, 2009, p. 18). Especially the price of coal exports from Colombia are not fully cointegrated with the rest of the market, this might be due to the fact that Colombia mainly exports to the U.S. whose market was not looked at in their paper.

In their 2006 paper Bachmeier and Griffin address the question if there is one integrated energy market for coal, oil and gas. To answer this question they resort to the error correction model but do not use tests for cointegration. While they find significant values for the error correction model, they argue that these are too small to be used as evidence for market integration. They furthermore state that the link between gas and oil prices are the strongest but still not strong enough to speak of one market. As they do not test the variables for cointegration using standard test such as the Engle-Granger approach or the Johansen Test their analysis seems flawed. If there would be no cointegration the regression between the price series would be spurious thus its residuals should not be used for further analysis. Another problem in their analysis is that they use American coal prices in order to check for market integration, it will be shown below that the American coal market is less integrated in a global coal market than other regional markets, therefore it would be useful to check for market integration between gas and oil prices and a different coal price.

4.6 Cointegration Analysis: Is there a Worldwide Coal Market?

This section of the thesis is using the previously introduced techniques to determine if the worldwide coal market can be considered as one integrated economic market. Furthermore it uses an error-correction model to present and discuss price dynamics between several local coal prices. First the data used in this chapter is presented before two different tests for cointegration are used to determine which coal price time series can be considered cointegrated. Those price series are then used to create an error correction model to further understand the short and long-term dynamics of the coal price in these locations. Finally, the results of the two tests and the error correction models are discussed and the need for further research is addressed.

4.6.1 Data

The data used in this chapter to test for cointegration of steam coal prizes are quarterly C.I.F. prices of steam coal published by the International Energy Agency in their quarterly report on "Energy Prices and Taxes". They cover the time period from the first quarter of 1980 to the second quarter of 2009, there are thus 114 observations. The import prices of Japan, as the worlds biggest coal importer, the European Union and the United States, the other most important coal consumers are used to test whether there is a global integrated market for coal. As these countries account for more than half of all steam coal imports (World Coal Institute, 2009) a conclusion that their coal prices are cointegrated would be a strong indication for a world wide coal market. As usual in papers using cointegration to test for market integration all prices are expressed as natural logarithms. While data with a higher periodicity would be preferable the IEA data was the best available recent data that was comparable between the three locations.

4.6.2 Results: Two Step Engle-Granger Approach

As a first test of pair wise cointegration of the three price series the two step Engle-Granger is used. To begin it is necessary to check whether the price series are $I(1)$ processes. To do this a Dickey-Fuller test for unit-roots is performed on the price series and their first differences. If this test does not reject unit-roots for the price series but rejects them for their first difference the time series can be assumed to be $I(1)$ processes. The results of the tests are presented in the following table:

	DF Test on price	DF Test on first differences
Japan	0.450	-5.422***
Europe	-0.349	-7.700***
United States	-0.488	-11.844***

Table 1: Results DF Test for Unit-Roots - Critical Values: 1% : -3.43 - 5% : -2.86 - 10% : 2.57

The Results in Table 1 show that Unit-Roots for none of the price series can be rejected but are all easily rejected for their first differences at a 1% significance level. Therefore all time series can be assumed to be $I(1)$.
Next a cointegration equation of the form of

$$Y_t = \beta X_t + \gamma + e_t \tag{9}$$

will be estimated using standard OLS. While these estimates, as documented above, are super consistent they do not obey a normally distribution and thus hypothesis testing with them is not possible. The residual can however be used to test for cointegration and to estimate an error correction model. This technique has the problems that the results depend on which variable one declares exogenous X_t and which is the endogenous variable, Y_t. While this makes sense in some cases of cointegration in ours it is at least not obvious which price should be the exogenous one. Therefore the parameters of all possible combinations are estimated and presented in the following table which states the estimates for β, γ and the R^2 of the model. As the estimates are non-normally distributed no standard deviations, or significance levels are presented.

Y_t	X_t	β	γ	R^2
Japan	Europe	0.903	0.367	0.885
Europe	Japan	0.980	0.092	0.885
Japan	United States	1.181	-0.427	0.618
United States	Japan	0.523	1.628	0.618
Europe	United States	1.226	-0.566	0.610
United States	Europe	0.499	1.716	0.610

Table 2: Results OLS Estimation of the Cointegration Equation

While no hypothesis testing is possible, some differences between the equation are apparent: The R^2 of the relationship between Japanese and European prices are significantly higher than for the other relationships. Furthermore only these equations have a β which is not very far away from unity. Therefore they seem at least more in line with the "Law of one Price" which should prevail in integrated markets. In order to test for cointegration it is now necessary to test the residuals of the equation above for stationarity. If they are stationary the variables can said to be cointegrated. This is done again by an Dickey-Fuller test. It is however necessary to use other, more negative, critical values as the model is fitted to minimize the residuals and thus make them "look more stationary".

Y_t	X_t	Result of DF Test on Residual
Japan	Europe	-3.149*
Europe	Japan	-3.397*
Japan	United States	-2.846
United States	Japan	-3.017
Europe	United States	-2.948
United States	Europe	-2.864

Table 3: Results DF Test on the Residuals of the Cointegration Equations - Critical Values: $1\% : -3.51$, $5\% : -3.34$, $10\% - 3.04$

Using asymptotical critical values for this residual-based unit roots test provided by Davidson and Mackinnon (1993) only the values for both relationships between Europe and Japan are over the 10% significance value of -3.04. The value for Europe as the dependent and Japan as the independent variable is close to the 5% significance value of -3.34. It is however necessary to say that these test work with the null hypothesis of a unit root and thus a failure to reject H_0 does not necessarily mean that the values are not cointegrated. Another shortcoming with the Engle-Granger two step approach is that the power of the test is relatively low for smaller data sets. It can be concluded that, according to the Engle-Granger two step approach to test for cointegration, C.I.F. import prices for steam coal in Japan and the Europe Union are indeed cointegrated in both directions. This method could not find cointegration between the prices in the United States and Europe and Japan respectively.

4.6.3 Results Johansen Test for Cointegration

As the two step Engle-Granger method to test for cointegration has some shortcomings such as lacking power for smaller samples and the problem that one variable has to be declared dependent and one independent. This paper also uses the Johansen test for cointegration to confirm the results of the previous section.
To do so the Johansen cointegration test for cointegration is done on all pairs of the three price series using the vecrank command in Stata and lags chosen according to the Schwarz' Bayesian information criterion. Furthermore the model is specified without a trend component. The trace statistic results of this test and the number of lags used are presented in the following table. The trace statistic is a test with a H_0 that the rank of Π is smaller or equal than r

	Japan - EU	EU - USA	Japan - US	5% crit. val.
r<= 0	19.9203*	21.4030*	16.3385*	12.53
r<= 1	0.0171	0.3436	0.2402	3.84
lags	2	1	2	

Table 4: Results of Johansen Test for Cointegration

According to the Johansen test for cointegration all of the variables would be cointegrated as the trace statistics for $r <= 0$ all reject the H_0 and the next step, using the H_0 of $r <= 1$, fails to reject the H_0. Thus all Π are of rank 1 and there is one cointegration vector for all the price pairs. This confirms the finding from the Engle-Granger two step approach that the prices in Europe and Japan are cointegrated. It does however not confirm the previous approach concerning both price pairs with the United States. While the Engle-Granger approach above failed to find cointegration for these pairs the Johansen test did so at a 5% significance level. As previously mentioned the Engle-Granger approach is considered to lack power when using on a rather small sample. Therefore it must be assumed that all price pairs are cointegrated and thus stay in a long-term equilibrium, to better understand their relationship the next section will develop error correction models that describe their short time movement and relationship.

4.6.4 Error Correction Model of the Price Dynamics of Global Steam Coal Prices

As discussed above two or more time series that are cointegrated are following an error correction model. This model can help to understand not only the long-term equilibrium between these two variables but also their short-term responses to deviations from this equilibrium and movements of the other series. Using the estimates for the cointegration equation from the two step Engle-Granger approach and their residuals three different basic error correction models will be estimated in this chapter to better describe the relationship between the regional steam coal prices. The estimated cointegration equations where respectively:

$$Price_{t,Japan} = 0.90Price_{t,Europe} + 0.37 + E_t \tag{10}$$

$$Price_{t,Europe} = 0.98Price_{t,Japan} + 0.09 + E_t \tag{11}$$

$$Price_{t,Japan} = 1.18Price_{t,UnitedStates} - 0.43 + E_t \tag{12}$$

$$Price_{t,UnitedStates} = 0.52Price_{t,Japan} + 1.63 + E_t \tag{13}$$

$$Price_{t,Europe} = 1.22Price_{t,UnitedStates} - 0.57 + E_t \tag{14}$$

$$Price_{t,UnitedStates} = 0.50Price_{t,Europe} + 1.72 + E_t \tag{15}$$

All error correction models use the lagged error term of these equations to explain the movement of one of the prices. The simplest error correction additionally only uses the movement of the other price series as an independent variable. Other models include lags of the price movements of the two series. This paper will use two different kinds of these models plus a third model which combines the two other models in order to check which is the best fit for the dynamics governing the coal market. To do this all of the three models will first be estimated for all of the price pairings. After this the main results for each of the pairing will be discussed.

At first, a simple model of the form which is also used by Bachmeier and Griffin (2006) will be applied:

$$\Delta Y_t = \beta_0 \Delta X_t - \Phi Z_{t-1} \tag{16}$$

Where Z_t stands for the residual of the cointegration equations. As stated above, standard OLS leads to consistent normally distributed estimators. The estimates of the parameters of this error correction model are stated in the Table 5.

Y_t	X_t	β_0	Φ	R^2
Japan	Europe	0.371*** (0.061)	-0.307*** (0.045)	0.522
Europe	Japan	0.734*** (0.112)	-0.085 (0.070)	0.339
Japan	United States	0.181** (0.091)	0.008 (0.035)	0.042
United States	Japan	0.188** (0.094)	-0.177*** (0.051)	0.134
Europe	United States	0.154 (0.105)	0.017 (0.038)	0.029
United States	Europe	0.105 (.084)	-0.198*** (0.051)	0.140

Table 5: Estimates for the Basic Error Correction Model

Other authors such as Warell (2006) use an error correction model which includes the first lags of the price series but does not include the movement of the other price in the same period:

$$\Delta Y_t = \beta_1 \Delta Y_{t-1} + \beta_2 \Delta X_{t-1} + \Phi Z_{t-1} \tag{17}$$

which leads to the estimates presented in Table 6.

Y_t	X_t	β_1	β_2	Φ	R^2
Japan	Europe	0.323*** (0.077)	0.220*** (0.081)	-0.231*** (0.051)	0.556
Europe	Japan	0.133 (0.128)	0.150 (0.125)	0.112 (0.082)	0.123
Japan	United States	0.650*** (0.088)	-0.0793 (0.0734)	-0.050* (0.028)	0.337
United States	Japan	-0.112 (0.094)	0.218** (0.106)	-0.151*** (0.054)	0.138
Europe	United States	0.337*** (0.100)	-0.0792 (0.0961)	-0.012 (0.037)	0.101
United States	Europe	-0.071 (0.093)	0.0494 (0.093)	-0.192*** (0.056)	0.132

Table 6: Estimates for the Error Correction Model with one Lag

The third error correction model used in this thesis is a combination of the two above and uses both, the lagged first differences of both prices as well as the first difference of the exogenous price series in the same period. This model has the following specifications:

$$\Delta Y_t = \beta_0 \Delta X_t + \beta_1 \Delta Y_{t-1} + \beta_2 \Delta X_{t-1} + \Phi Z_{t-1} \tag{18}$$

and leads to the estimates presented in table 7

Y_t	X_t	β_0	β_1	β_2	Φ	R^2
Japan	Europe	0.299***	0.266***	0.201***	-0.175***	0.662
		(0.052)	(0.069)	(0.071)	(0.046)	
Europe	Japan	0.813***	-0.0575	-0.0607	-0.069	0.346
		(0.132)	(0.115)	(0.114)	(0.0760)	
Japan	US	0.110	0.633***	-0.064	-0.063**	0.350
		(0.0753)	(0.088)	(0.074)	(0.030)	
US	Japan	0.123	-0.103	0.144	-0.154***	0.147
		(0.117)	(0.095)	(0.127)	(0.053)	
Europe	US	0.150	0.336***	-0.060	-0.034	0.118
		(0.102)	(0.100)	(0.096)	(0.040)	
US	Europe	0.100	-0.064	0.019	-0.189***	0.142
		(0.0889)	(0.093)	(0.097)	(0.056)	

Table 7: Estimates for the combined Error Correction Model

The results of the estimations of the ECM will be discussed first for the relationship between prices in Japan and Europe which seem to be in a closer connection than the the two other pairs which will be discussed after this:

The ECM for Japanese and European Steam Coal Prices In order to explain the movement of the European price with the Japanese price as the independent variable it seems that only the price movement of the Japanese price in the same period has a significant impact, all other estimators are not significantly different from zero. The Japanese price movement however yields a R^2 of over a third, adding further lags of the price movements does not improve the model significantly. This correlation indicates that price movements in Europe and Japan are very connected as much of their movements is synchronized. Some of these changes that happen in both markets could however be due to other external factors such as business cycles, weather conditions etc. Therefore this relationship alone does not confirm the thesis of one integrated

market. Furthermore no model finds a significant error correction mechanism which would pull the European price back to the long-term equilibrium.
Looking at the Japanese price one comes to completely different conclusions. Here all the estimations for the parameters of the third model produce significant results, adding further lags however improves R^2 only slightly and does not produce any significant estimates for lagged the parameters. The use of one lag for the movement of the Japanese price series and no lags for the movement of the European series is also confirmed by the Schwarz' Bayesian information criterion. To describe the short-term movements of the Japanese price it seems therefore best to use the third error correction model which yields the following conclusions: While the movement in the European price in the same period still plays a role, the price movements in the past period, if included in model, and even more so the deviation from the long-term equilibrium play central roles in the price dynamics. The lagged residual of the cointegration equation alone would already yield a R^2 of 0.37 and thus can be said to play a substantial part in the movement of the Japanese price. If the model of equation 18 is used, Φ, the error correction parameter, is estimated to be -0.18. Thus 18% of a deviation from the long-term equilibrium is reduced in the following period. This value is even higher for the first model. The result that the European and Japanese price are relatively closely connected can also be supported by the estimations of their cointegration parameters in table 2. They are relatively close to unity and thus would be in line with the law of one price.

The ECM for the pairings with the United States The two pairings of regional prices including the United States are significantly different in their short-term responses than the pairing of Europe and Japan. The low R^2 of the first model for the movements of the Japanese and European prices with the United States as the exogenous variable is the most significant difference. Only 4.2% and 2.9% of their movements can be explained by the error correction term and the movement of the American import price for coal. Furthermore almost all of the estimators are not significant. This leads to the conclusion that the American price for coal has no or almost no influence on the movements of the coal price in Japan and the European Union. Looking at the coal price movements in the United States it is important to note that the estimators for the error correction mechanism are significant in all three models. The estimator for the error correction mechanism factor for the models with Japanese as the dependent and the United States as the independent variable is also significant for the third model. This estimator is however much smaller than the one describing the error correction mechanism changing the American coal price. While only about 6% of the deviation of the equilibrium between Japan and the

United States is reduced by a movement in the Japanese price, 15% and 19% of the deviations from the equilibrium between the American and the other prices are reduced by movements in the American coal price. Therefore it can be concluded that the American coal price adapts to deviation from its long-term equilibrium with the Japanese and the European price to a similar degree as the Japanese price does to a deviation from the long-term equilibrium with the European price. But here it is important to note that the R^2 is far lower than for the relationship between Japan and Europe. Thus while it seems that there is an error correction mechanism at work it seems less strong than for the case when the relationship of Japan and Europe is considered. Again this can also be supported by the estimations of the cointegration equations which estimated the cointegration parameters to be relatively far away from unity.

4.6.5 Discussion of the Results

According to the results of this section the prices for imported steam coal in Europe, Japan and the United States are all cointegrated. At the same time it has to be said that only one of two tests found this cointegration between the United States and the other two regions. It therefore seems that these prices are less cointegrated than the prices in Japan and Europe. Using an error correction model to further describe the price dynamics between these regions this paper came to some other results: First the error correction model supports the theory that prices between the United States and the other two regions are in a looser relationship than prices in Europe and Japan. This is best visible by the small R^2 of the error correction model describing this relationship, which indicates that these prices only have a limited impact on each other's movements. The relationship between the Japanese and European price on the other hand seems relatively close, around two thirds of the movements of the Japanese coal price can be explained by movements of it self in the preceeding period, movements of the European coal price and deviations from the long-term equilibrium relationship between these prices. Furthermore it is interesting to note, that for each bivariate model, except for the relationship between Japan and the United States, only one of the estimators for error correction mechanism is significant. This implies that for each pair wise relationship there is one country which does the major part of adaption if their prices are no longer in an equilibrium. But even though the estimators for the relationship of the Japanese and American coal price find that both error correction models produce significant error correction term estimators one of them is far higher thus even in this case there is a big asymmetry between the price pairs.

4.7 Is there a Worldwide Market for Primary Energy Sources?

This part of this thesis tries to address the question if there is one integrated worldwide market for primary energy fuels, which was also addressed by Bachmeier and Griffin (2006) and mentioned in chapter 2. Here it is interesting to see if the hypotheses introduced in chapter 2, that the markets for oil, gas and coal are not integrated in the short-term and gas and coal might be connected in the long-term can be supported by econometric analysis. It seems unlikely that energy prices in the short term are closely linked as substitution between energy sources takes time and is costly. It seems however not unreasonable to check whether there exists a long-term equilibrium between oil, gas and coal prices as all of these fuels serve a similar purpose and might be substituted in the long term. Such an equilibrium, if found, would be a help in order to describe the dynamics governing the coal market. The method of Bachmeier and Griffin (2006) to test this, they estimate an error correction model between the prices without testing for cointegration first, seems flawed. Bachmeier and Griffin just use the coal prices in the United States and not the prices of a more open coal market. This part of the thesis therefore uses the methods presented above to verify if coal prices are cointegrated with oil and gas prices. Thus a different methodology and different data sets are used than in the Bachmeier and Griffin paper.

4.7.1 Data

To test the hypothesis about a global integrated market for primary energy sources this paper uses monthly price data provided by the International Monetary Fund (IMF) for thermal coal exports of Australia as proxy for a global coal price, prices for Russian natural gas in Germany and a proxy for a global oil price: an average of U.K. Brent, Dubai, and West Texas intermediate also compiled by the IMF. The data is available from January 1985 to December 2009 and thus includes 300 Observations. The natural logarithms of all prices are used.

4.7.2 Results two Step Engle-Granger Test

First the Engle-Granger two step approach is used to test the hypothesis of cointegration between the variables, as the steps are virtually identical to the section above only their results will be presented. To begin with it has to established that all variables are $I(1)$, the results of a Dickey-Fuller test for the price series and their first differences is presented in table **??**tab:ResultsADFEnergy

These results confirm that all the price series are $I(1)$ thus one can proceed to

	DF Test on price	DF Test on first differences
Coal	-0.357	-12.417***
Oil	-0.729	-12.361***
Gas	-0.748	-15.800***

Table 8: Results DF Test for Unit Roots - Critical Values: 1% : -3.43 - 5% : -2.86 - 10% : 2.57

the next step of the Test, the estimation of the cointegration equations of the form:

$$Y_t = \beta X_t + \gamma + e_t \tag{19}$$

The results of this estimation are presented in the table below:

Y_t	X_t	β	γ	R^2
Coal	Gas	0.552	1.024	0.589
Gas	Coal	1.067	0.876	0.589
Coal	Oil	0.542	1.909	0.618
Oil	Coal	1.139	-0.936	0.618
Oil	Gas	.836	2.0795	0.7590
Gas	Oil	0.908	-1.109	0.7590

Table 9: Results OLS Estimation of the Cointegration Equation

As described above only the residuals of this equation are useful to test for cointegration. A Dickey Fuller test was used to test for their stationarity, the results are presented below:

Y_t	X_t	Result of DF Test on Residual
Coal	Gas	-2.243
Gas	Coal	-2.007
Coal	Oil	-2.269
Oil	Coal	-2.428
Oil	Gas	-3.459**
Gas	Oil	-3.422**

Table 10: Results DF Test on the Residuals of the Cointegration Equations - Critical Values: $1\% : -3.51$, $5\% : -3.34$, $10\% - 3.04$

According to these values only the prices of coal and gas are cointegrated at a 5% significance level (in both directions). There is no evidence for cointegration between the coal price and one of the other fuels. As mentioned above this is no evidence that is speaking against cointegration between these values therefore a Johansen Test for cointegration is also used to verify these results and prevent some possible problems arising under the Engle-Granger two step Approach.

4.7.3 Results Johansen Test

The Johansen test is conducted in the same way as in the section about coal market integration. Therefore the lag length is selected with the Schwarz' Bayesian Information Criterion and no trend is included. And the trace statistics and its critical values for this setup are presented in order to determine the rank of Π and thus to test whether the variables are cointegrated.

	Coal - Gas	Coal - Oil	Oil - Gas	5% critical values
Trace stat. rank <= 0	13.5303**	10.3664	29.8556**	12.53
Trace stat. rank <= 1	0.2806		0.2097	3.84
lags	4	2	4	

Table 11: Results of Johansen Test for Cointegration

These results confirm the findings of the Engle-Granger approach that the oil and gas prices are cointegrated. The Johansen test also does not find cointegration between coal and oil prices. It does however find evidence for cointegration between the gas and coal prices which was not the case for the Engle-Granger approach. But as the H_0 of the Engle-Granger approach is no cointegration a failure to reject is not enough to reject the idea of cointegration. Therefore it has to be concluded cautiously that the gas and coal price are cointegrated and thus have a long-term equilibrium in their price levels.

4.7.4 Error Correction Model for the Relationship between the prices for fossil fuels

Following the logic of the previous chapter an error correction model will be used to describe the relationship of the coal and gas price series chapter to analyze their relationship in further detail. While the relationship between the oil and gas prices are not the principal topic of this thesis an error correction model governing their relationship will also be estimated in order to have a comparison for the error correction model for the relationship of the coal and gas price
The error correction model of equation 18 will be used in this chapter and the rest of the methodology will be the same as in the previous chapter. The estimates for the model are presented in the table 12.

Y_t	X_t	β_0	β_1	β_2	Φ	R^2
Coal	Gas	0.024	0.329***	0.029	-0.023*	0.112
		(0.046)	(0.056)	(0.045)	(0.013)	
Gas	Coal	0.036	0.089	0.063	-0.026**	0.0310
		(0.074)	(0.58)	(0.074)	(0.011)	
Oil	Gas	-0.065	0.3563***	0.020	-0.032	0.116
		(0.081)	(0.061)	(0.075)	(0.022)	
Gas	Oil	-0.048	0.042	-0.095	-0.102***	0.154
		(0.042)	(0.054)	(0.046)	(0.015)	

Table 12: Estimates for the combined Error Correction Model

The results of the estimation for the error correction model governing the dynamics of the relationship between the price of coal and the gas price primarily indicate that while the prices are cointegrated, and thus in a long term equilibrium, they are not closely related in the short term. Both of the estimations above have a relatively small R^2 thus the movements in the prices of the two commodities cannot be said to be closely related. Furthermore the parameter describing the error correction mechanism is only significantly different from zero at a 10% significance level for the model describing the coal price movement. The parameter is significant at a 5% level for the model explaining the movements of the gas price. But both values are relatively low indicating that only 2 to 3 percent of a deviation from the long-term equilibrium will be reduced in the next period. This value is far higher for the model explaining the gas price movements through the oil price where 10% of a deviation are reduced in the following period. Furthermore the two models including gas and oil prices have a higher R^2 than the models including the coal and gas price.

4.7.5 Discussion of the Results

The results in this section are in line with the research done by Bachmeier and Griffin who stated that the link between gas and oil is stronger than the links between the coal price and one of the other two fuels. While it can be shown that coal and gas prices are cointegrated, at least according to one of the tests used, an error correction model describing their short-term dynamics indicates that they are not closely related in the short term. The coal and oil prices on the other hand are not even cointegrated and thus cannot considered to be even in a long-term equilibrium relationship. It can therefore be assumed that to understand the short-term dynamics of the coal price it is not important to relate its price to the prices of the other primary fossil fuels. However gas and coal price seem to be linked to a long-term equilibrium, therefore it is important to also understand the dynamics governing gas prices to understand the long-term dynamics of the coal price.

4.8 Limitation and Questions for Future Research

While the preceding chapter offered more insights in the structure and dynamics of the coal market, these results have to be put in perspective by highlighting some possible problems with the data and the methods used to come to the conclusions mentioned above. The critique brought by McNew and Faller (1997) that cointegration alone is not enough to prove market integration has to considered seriously. The cointegration of the three respective price series analyzed in the first part, some only found by one of the two tests used, is not enough to prove that there is indeed an integrated market. On the other hand, the findings of chapter four can be considered to support the results of the preceding part about coal market integration. Furthermore only three price series were used, further research should include more coal prices preferably in other regions and countries such as China or India, two very important coal markets which were not looked at in the section before. Additionally data with higher frequency would have been better to provide robust test results. Another point future research could address is the development of coal market integration, it would be interesting to know in which direction coal market integration was developing in the past years. The second part of the previous chapter mainly suffered from similar shortcomings as the first part, the two tests delivered partly different results, thus questioning the robustness of their outcomes. While the data had a higher frequency than in the first part, monthly instead of quarterly results, it was still relatively lower and higher frequencies would be preferable. Furthermore the inclusion of more indicators for the coal price would be useful, as coal prices in different regions, while cointegrated in the long-term, might deliver different results. Furthermore it would also be useful to look at the temporal developments in the relationship between the prices for the primary commodities in order to better understand the dynamics of their relationships.

5 Conclusion

This paper aimed to present the structure and price dynamics of the global market for coal, focusing especially on steam coal, a form mainly used for power generation. The first part of this thesis concludes that, even in times of climate change debate, coal is and can be expected to remain one of the most important fuels for power generation. This is mainly due to its widespread reserves, relatively cheap price and the fact that coal is especially prevalent in developing countries, which are expected to grow most in the mid-term. New improvements to the efficiency of coal-fired power plants are however essential in order to reduce coal's emissions. Other technologies, such as CCS, are promising but their success is still uncertain. Furthermore the relationship between coal and other primary energy fuels, mainly oil and gas, seems rather loose as their use differs substantially. Thus the idea of one single market for primary energy fuels does not seem to be plausible, which was also confirmed by using time series econometrics from which the results are presented below.

A first qualitative analysis of the structure of the coal market came to the following conclusion: there are several regional coal markets, which are separated to a certain degree. The US and China, the world's two largest markets for coal, are almost entirely domestic and play only a limited role in international trade in coal. This leads to only 16% of coal consumption being traded internationally. The largest players in international coal trade are Australia and Indonesia, which mainly export to the Pacific market, mainly consisting of Japan, South Korea and Taiwan. The second most important market for imported coal is Europe, which mainly imports from Colombia, South Africa and the Ukraine.

In order to better understand the connection between these markets this paper used time series econometrics, namely cointegration analysis and error correction models. Firstly, import price data provided by the International Energy Agency were used in two tests for cointegration. Then an error correction model was estimated in order to analyze the price dynamics between these regions.

The results of these tests correspond closely with the more qualitative description of the coal market in the second chapter: the market for coal can be considered to be integrated between Japan and the European Union and only to a lesser extent between these two large regional import markets and the United States. Furthermore Europe seems to be the price leader and the coal price in Japan seems rather to follow and adapt to developments of the coal prices in the European market. Nevertheless, according to one of two tests, all the three prices can be considered to be cointegrated and thus in a long-term equilibrium. Therefore one could speak, at least in the long term, of one single worldwide market for coal. In the short term however important deviations of this equilibrium are, possible and relatively frequent. This can be also explained by the findings of the qualitative part of this thesis, transport rates for coal are relatively high, making it more expensive to ship to other markets than those which are closest. Furthermore most exporters ship the largest share of their coal to either the European or Pacific market, thus they do not always have, at least in the short term, the opportunity to take advantage of price differences.

Regarding the relationship between the primary fossil fuels, the idea of one single market for primary fossil fuels cannot be supported by the evidence provided in this thesis: while both coal and gas prices and gas and oil prices are found to be cointegrated, thus being in a long-term equilibrium, no such equilibrium can be found for coal and oil prices. In addition all these relationships are very loose in the short term. The relationship between oil and gas turns out to be significantly closer but still not close enough to be considered to be part of one market. The relationship between gas and coal seems to be even looser; forces that pull these prices back to their equilibrium estimated by an error correction model were extremely low. The coal and oil prices are not even found to be cointegrated, thus there is no evidence for them to be in long-term equilibrium. These results could be explained by the fact that steam coal and gas are more similar in their use than coal and oil, as both are primarily used for electricity generation while oil is mainly used for transport. Additionally a switch from coal to gas or vice versa is only possible in the mid-term, thus the relationship of their price is rather loose and short-term dynamics between them are quasi non-existent.

Furthermore this thesis showed that using tests for cointegration and error correction models to describe the regional structure and dynamics of commodity markets does provide additional information and helps to better understand their workings. Further research could be aimed at looking at market integration over time, thus checking whether the strong growth in the coal market has changed the market and rendered it more integrated. Additional price data from more locations, especially China, as well as more frequent data would have been useful. The approach of this paper in using only three locations to find evidence for a worldwide integrated coal market leaves some questions open, the relationship of the Chinese market with the three other markets discussed above would have been of particular interest.

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Eigenständigkeitserklärung

Ich erkläre hiermit,

- dass ich die vorliegende Arbeit ohne fremde Hilfe und ohne Verwendung anderer als der angegebenen Hilfsmittel verfasst habe,
- dass ich sämtliche verwendeten Quellen erwähnt und gemäss gängigen wissenschaftlichen Zitierregeln nach bestem Wissen und Gewissen korrekt zitiert habe.