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Trends and Super Cycles in Crude Oil and Coal Prices

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ABSTRACT

This paper uses the band-pass filter approach of Cuddington and Jerrett (2008) to (i) study longterm trends in crude oil and coal prices and (ii) to search for evidence of super cycles in these energy commodity prices. Although Cuddington and Jerrett found evidence of super cycles in metals prices, it is unclear a priori whether one would expect to find them for oil and coal due to differences in market structure and relative importance in the industrialization process during different epochs.

We find that long-term trends have varied over time, with real coal prices trending downward and crude oil trending upward in the post World War II period, with different implications on the depletion-technology battle. There appear to be four super cycles in coal prices over the period 1800–2009 (with two uncertain periods) and three super cycles in oil prices over the period 1861–2010 (with one uncertain period). These coal super cycles roughly match the timing of those for oil and metals prices after WWII—but not in the pre WWII period—and their timing suggests that they were caused by episodes of industrialization and urbanization in various countries or regions in the global economy. Thus, the post WWII evidence is consistent with the super-cycle hypothesis.

JEL codes: **E32, L71, Q41, E37**

Keywords: **Super Cycles, Long Cycles, Exhaustible Resources, Oil Prices, Coal Prices, Trend-Cycle Decomposition, Christiano-Fitzgerald Band-Pass Filter**

* We thank Diana Moss for extensive comments and suggestions.

TRENDS AND SUPER CYCLES IN CRUDE OIL AND COAL PRICES

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JEL Codes: E32 (Business Fluctuations, Cycles), L71 (Mining, Extraction, and Refining: Hydrocarbon Fuels), Q41 (Energy: Demand and Supply), E37 (Forecasting and Simulation: Models and Applications).

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I. Introduction

Given the importance of energy resources in the global economy, it is hardly surprising that the prices of energy products have been extensively studied. Long-term trends, behavior over the business cycle, sensitivity to geopolitical developments and causes of short-run volatility have all been of keen interest to policy makers, producers, consumers, and investors. Figure 1 provides long-term annual data on real coal prices from 1800 to 2009 and for real crude oil from the early 1860s (when its commercial use emerged) to 2010.

The surge in prices in the early years of the 21st century has generated much discussion about both long-term trends (peak oil?) and possible ‘super cycles’ (SC) in commodity prices. See, e.g., Rogers (2004), Heap (2005), Cuddington-Jerrett (2008), Jerrett-Cuddington (2008). Alan Heap (2005) defined SCs as “Prolonged (decades) long trend rise in real commodity prices.” The upswings of these SCs last 10-35 years as a large country or region goes through structural transformation associated with industrialization and urbanization. This structural transformation is accompanied by increased demand for energy commodities and metals as the manufacturing sector expands (see Kuznets (1973)). Cuddington and Zellou (2012) provide a formal model of super cycles driven by the structural transformation of a typical economy during the development process. They show that the presence or absence of SCs will depend critically on the speed of capacity adjustment to surging mineral demand during industrialization. Cuddington and Jerrett (2008; 2008; 2010) found evidence of SC in metals prices. Zellou and Cuddington (2011) study focused on super cycles in oil prices.

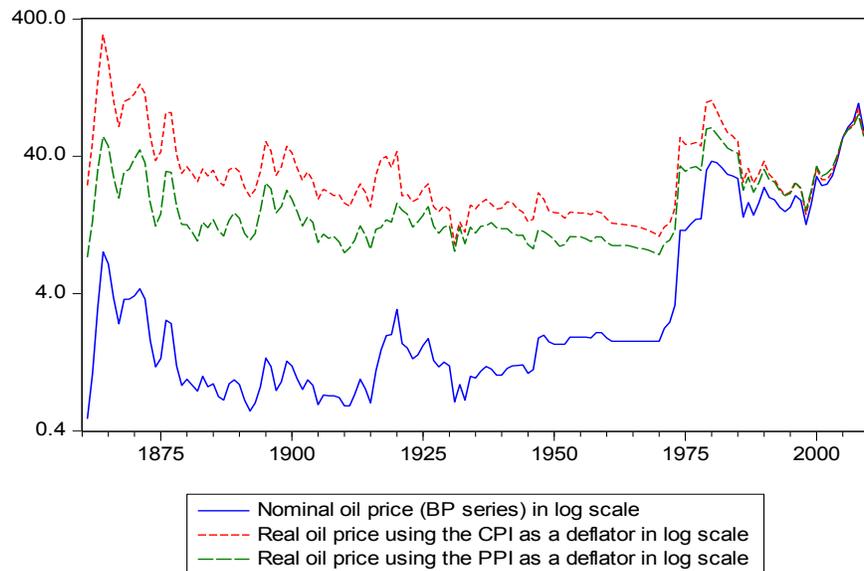
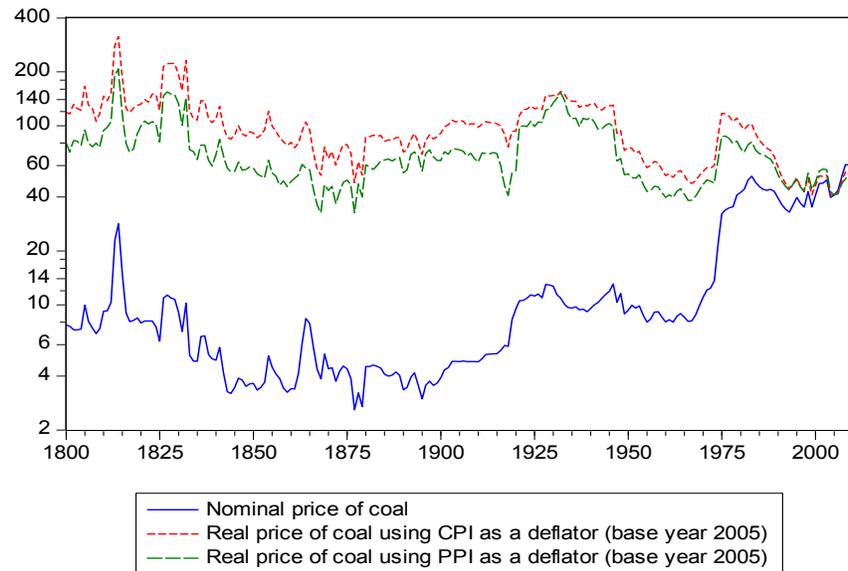


Figure 1: Nominal and real prices of coal (top panel) and oil (bottom panel) using the Consumer Price Index (CPI) and Producer Price Index (PPI) (base year 2005) as price deflators. The coal price series spans the period 1800-2009 and is in U.S. dollars per short ton of anthracite. Sources: For 1800-1969, U.S. Department of Commerce, *Historical Statistics of United States Colonial Times to 1970*. For anthracite prices for 1970-2009, EIA/DOE, *Annual Energy Review*, 2010. The oil price series covers the period 1861-2010 and is in U.S. dollars per barrel. Sources: BP statistics. Prices are displayed on a log scale.

This paper uses the band-pass filter approach of Cuddington and Jerrett (2008) to (i) study long-term trends in crude oil and coal prices and (ii) to search for evidence of super cycles in these energy commodity prices. Although Cuddington and Jerrett found evidence of super cycles in metals prices, it is unclear *a priori* whether one would expect to find them for oil and coal due to differences in market structure (which will affect the speed of price and capacity responses to surges in mineral demand) and their evolving importance in the industrialization process during different epochs.

Section II provides background on the crude oil and coal markets to put our econometric analysis into context. Section III describes the data and band-pass filter methodology to extract SCs in coal prices. Section IV discusses the empirical results regarding the trend and cycles in coal and oil prices. Section V concludes.

II. Crude Oil and Coal Markets

Fossil fuels (coal, oil and natural gas) have been the main sources of energy since the Industrial Revolution. Figure 2 displays the evolving role of each fossil fuel in U.S. energy consumption since 1850. Coal was the main source of energy up to about 1950 when it was overtaken by oil. The latter stabilized at around 40% of U.S. primary energy consumption after 1950 (See Figure 2). At the world level, oil and coal represented about 60% of total primary energy supply in 2009. It was 70.6% in 1973 and is estimated to remain about 59% through 2035 (International Energy Agency (IEA) 2011). About half of the increased use of energy over the last decade came from coal!¹ (IEA 2011). Fossil fuel use (coal, crude oil and natural gas) represented 80% of total primary energy supply in 2010 and this share is expected to remain

¹ IEA, *2011 World Energy Outlook* (November 2011).

roughly unchanged through 2035, according to forecasts by the IEA. Alternative energy production is growing, but its *share* of global energy consumption is expected to remain roughly unchanged over the next 20 years. The bottom line appears to be that oil and coal will remain the primary energy resources years to come and the evolution away from fossil fuels will be slow.²

The structures of these two major energy commodity markets are different, which may have an effect on how these industries respond in terms of pricing and capacity adjustments to surges in demand associated with industrialization and urbanization. This paper does not attempt to model the role of market structure in how (if at all) prices evolve over time. However, a short description of crude oil and coal market structures may nonetheless be helpful in understanding and extending the results obtained from our trend-cycle decomposition analysis.

The crude oil has been characterized by market concentration and the exercise of market power throughout its history, beginning with the monopoly developed by John D. Rockefeller, followed by the “Seven Sisters,” and more recently the Organization of Petroleum Exporting Countries (OPEC).³ The current global crude oil market is cartelized under OPEC with a competitive fringe (international oil companies). Numerous recent studies focus on the structure of the oil industry. See, e.g., Cairns and Calfucura (2010), Smith (2002, 2009), Hamilton (2008, 2009), Krichene (2002) and Fattouh (2007)

² Appendix A provides a brief history of coal with a focus on the United States based on information from the American Coal Foundation. Appendix B presents similar information for oil.

³ The “Seven Sisters” includes the seven large Anglo-American multinational oil companies: Esso, Gulf, Texaco, Mobil, Socal, British Petroleum, and Royal Dutch Shell. OPEC is the Organization of Petroleum Exporting Countries. See Dahl (2004), Hamilton (2011) and Yergin (1991) for a comprehensive history of the oil market. Price determination in the oil markets was also influenced by regulatory interventions, such as those undertaken by the Texas Railroad Commission.

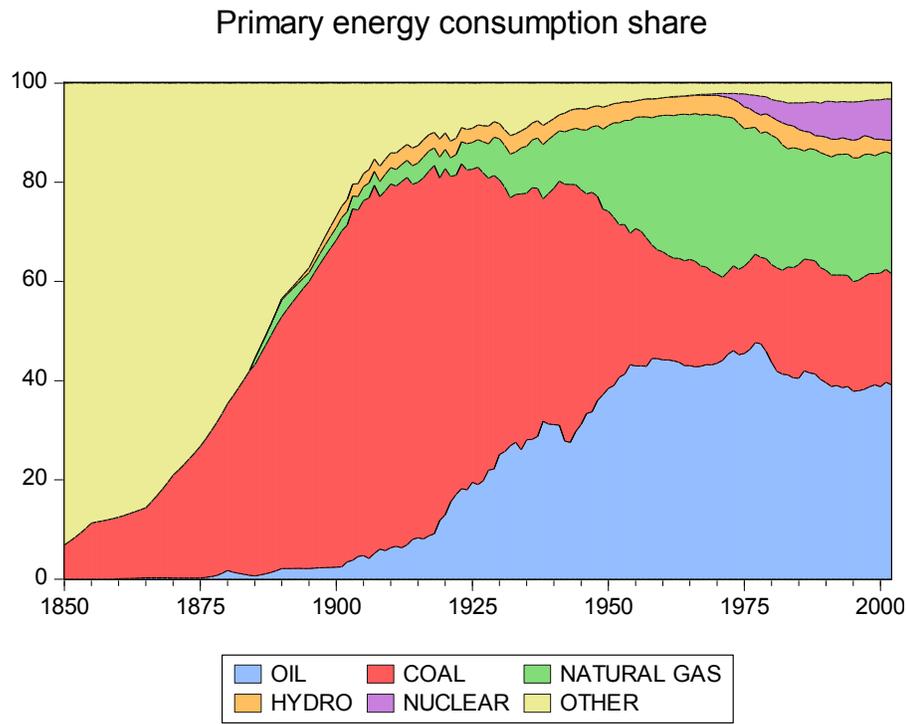
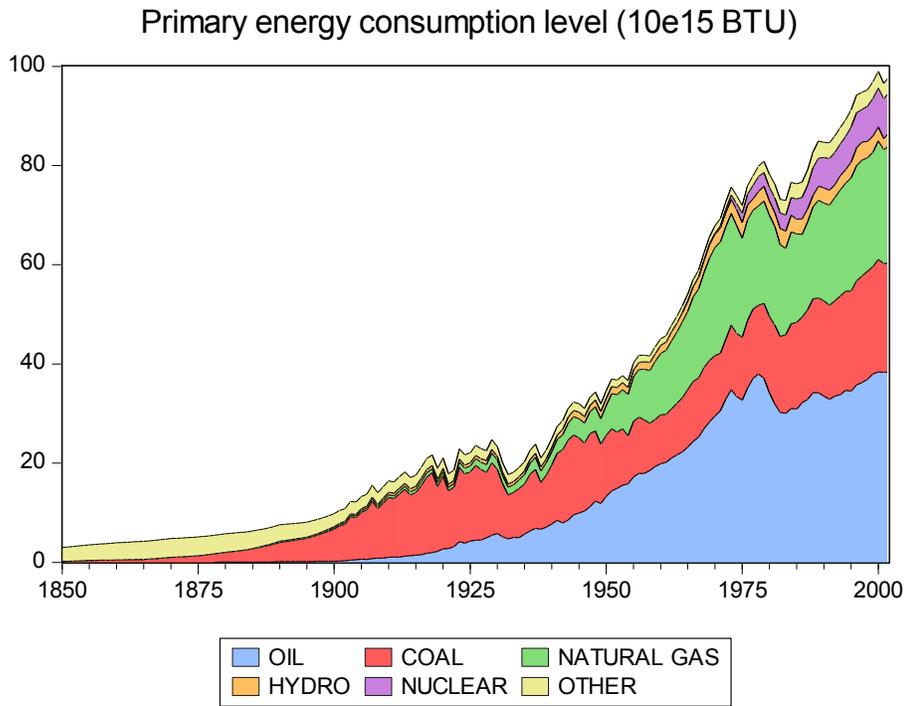


Figure 2: Primary energy consumption level (top panel) and share (bottom panel) for the United States between 1850 and 2010. Fossil fuels (oil, coal and natural gas) represent about 80% of the total energy consumed since 1900. That consumption is for all sectors of the economy from transportation to the industrial sector. Source: Tol (2006).

The market for coal is more competitive. Dahl (2004) provides a good description:

Although not every coal consumer is able to buy from every coal producers because of transportation costs, excessive profits in one mining area are likely to bring new entrants in the form of other coal producers or other energy sources. This threat to entry by other producers is referred to as *market contestability*. As the coal industry is a global industry and coal is the second largest product by weight to be traded internationally, this contestability can come from large foreign producers as well as other domestic companies. Such international contestability may have increased in recent years as transportation costs have decreased.

Coal is the second largest product traded internationally. Internationally traded coal currently accounts for roughly 16% of total coal consumed.⁴ Thus, coal markets are much less global than oil, having instead a domestic or regional orientation. There are, however, competing markets within each of the domestic markets for the major coal producers.⁵ Slade (1992); Jacks, O'Rourke, and Williamson (2009); Höök et al. (2010); Ellerman (1995) all provide excellent analysis of the structure of the coal industry.

III. Data and Band-Pass Filter Methodology

Our data sources are summarized in Table 1. Coal is classified into four main types (lignite, sub-bituminous, bituminous, and anthracite), depending on the amounts and types of carbon it contains and on the amount of heat energy produced. Anthracite has the highest carbon content of the four types (86 - 97 percent)⁶ and is the focus of this paper -- even though

⁴ See World Coal Association for more information: <http://www.worldcoal.org/coal/market-amp-transportation/>

⁵ China, the United States and India represents respectively 48.3%, 14.8% and 5.8% of the total production of coal with several companies private or public companies producing the coal in each country. Source: BP statistical review of world energy 2011.

⁶ A complete description of the four types of coal is available on the Energy Information Agency website: www.eia.doe.gov

bituminous coal is more widely consumed -- because it has the longest available time series.⁷

The series covers the period 1800 to 2009 and represents the price of anthracite per short ton.

The annual oil price series is from the *BP Statistical Review* (2011). It begins in 1861, when oil was first commercialized, through 2010. To get this long- span series, BP spliced three different oil price series. The U.S. average oil price is used from 1861 to 1944. From 1945 to 1985, the oil price for Arabian light posted at Ras Tanura is used. Finally, from 1986 to 2010, the Brent spot price is used. The Arabian light series begins in 1945, while the Brent series begins in 1986.

Figure 3 displays the nominal and real prices of coal and oil using two different price deflators: the Producer Price Index for All Commodities (PPI) and the Consumer Price Index (CPI). An Oregon State University website publishes the longest span U.S. Consumer Price (CPI) Index series starting in 1774 on an annual basis (Oregon State University (2011)).

Table 1: List of data and sources used in this paper.

| Description | Units | Frequency | Range | Source |
|---------------|--------------|-----------|-----------------------|---|
| Oil price | \$/bbl | annual | 1861-2010 | BP statistics: http://www.bp.com/sectiongenericarticle.do?categoryId=9023773&contentId=7044469 |
| Coal price | \$/short ton | annual | 1800-2009 | EIA http://www.eia.doe.gov/emeu/aer/coal.html |
| Metals prices | | annual | varies with the metal | Alan Heap Database |
| PPIACO | | annual | 1800-2010 | Carter <i>et al.</i> (2006) and then FRED database |
| CPI | | annual | 1774-2010 | FRED database and oregonstate.edu/cla/polisci/download-conversion-factors |

⁷ Sources: For 1800-1969, U.S. Department of Commerce, *Historical Statistics of United States Colonial Times to 1970*. For anthracite prices for 1970-2009, EIA/DOE, *Annual Energy Review*, 2010. We thank Professor Dahl of the Colorado School of Mines for providing these data.

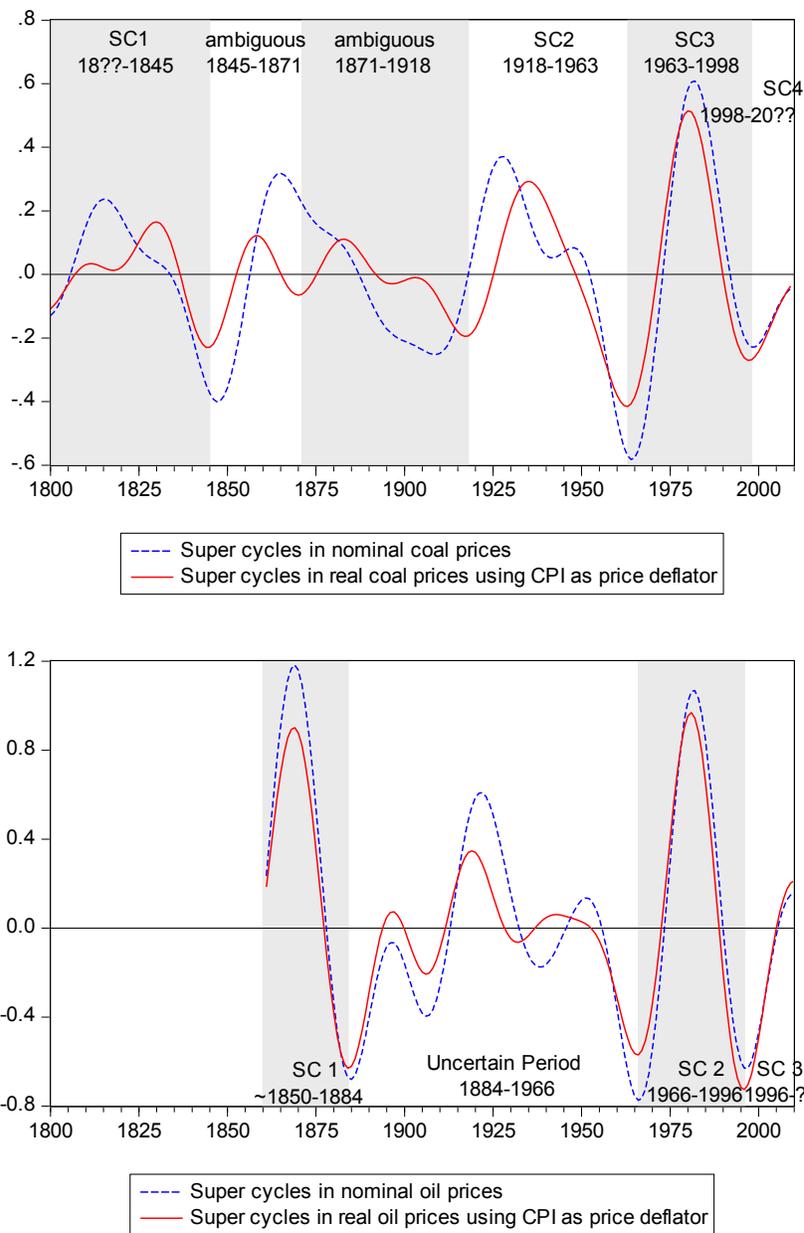


Figure 3: Super cycles in the nominal and real coal (top panel) and oil (bottom panel) prices (using the CPI as alternative deflators). The units on the vertical axis represent percentage deviations from trend. For example, +0.20 indicates 20% above the long-term trend. Note that the SCs in nominal and real prices are highly correlated, especially after World War II, suggesting that the SCs in real prices are not an artifact of movements in the price deflator. The shading corresponds to the different super cycles, measured trough to trough. Four SCs and two ambiguous periods are identified for coal: SC1: 18??-1845; ambiguous period 1: 1845-1871; ambiguous period 2: 1871-1918; SC2: 1918-1963; SC3: 1963-1998; SC4: 1998-20?? Three different SCs in crude oil prices are identified: SC1: 1861-1884; uncertain: 1884-1966; SC2: 1966-1996; SC3: 1996-20??

The ACF BP Filter is a univariate technique that allows the extraction of cyclical components from a given series.⁸ The use of band pass filters in economics has been promoted by Baxter and King (1999) and Christiano and Fitzgerald (2003).⁹ The band-pass or frequency filter extracts cyclical components of a given time series that lie within a specified ‘window’ or range of frequencies or (conversely) periods. The user specifies the lower and upper bounds of the periods of the cycles of interest, e.g. cyclical components with periods within the 20-70 year interval. Thinking of frequency filters in terms of time rather than frequency domain, Baxter and King explain that band-pass filters are sophisticated two-sided moving averages. They differ from the standard moving averages in two ways. First the (ideal) weights of various leads and lags are chosen to filter out cyclical components that do not fall within the chosen window. By choosing symmetric weights on each lead and corresponding lag, phase shift in the extracted component is prevented. Second, there are asymmetric as well as symmetric filters. Although asymmetric filters invariably introduce some phase shift into the filtered series, they have the advantage of allowing computation of the filtered series over the entire data span rather than being limited to a trimmed data span caused by the number of leads and lags used in calculating the filtered series. This is obviously advantageous if one is particularly interested in studying cyclical behavior near the end (or beginning) of the available data span.

The four different components extracted are the super-cycle, an ‘intermediate’ cycle, the business cycle and the trend component. The period ‘windows’ for these components are defined so that they are mutually exclusive and exhaustive, as shown in Table 2. (Note that the

⁸ Cuddington and Jerrett (2008) and Jerrett (2010) provide a good description of the use of asymmetric Christiano-Fitzgerald band-pass filter for SC analysis and apply it to the study of metals prices.

⁹ Similar band-pass filter techniques are used in different fields, e.g. hard sciences such as electronics and physics. The first author has encountered it, for example, in spectral imaging and spectral decomposition in geophysics in the oil and gas industry to extract 3D images of reservoirs in the presence of oil, gas or water.

seasonal component is not measurable with annual frequency data). The SC component, for example, has a window of 20 to 70 years. The trend component is defined to include all cyclical components beyond 70 years: $T(70, \infty) \equiv Actual - BC(2, 8) - IC(8, 20) - SC(20, 70)$.

Table 2: Period "windows" for the various cyclical components using annual frequency data.

| Cycle | | Annual |
|---------------------------|----|--------------|
| Business Cycle | BC | 2-8 |
| Intermediate Cycle | IC | 8-20 |
| Super Cycle | SC | 20-70 |
| Trend | T | 70- ∞ |
| Actual | | 2- ∞ |
| | | |

IV. Trends and Cycles in Oil and Coal Prices

Figure 4 displays the business cycle, intermediate cycle, super-cycle and trend components for the real coal and oil price series.¹⁰ A comparison of the long-term trend components of the two energy commodities is interesting in light on ongoing discussions about increasing scarcity of nonrenewable resources, peak oil, etc. For the real price of coal, the trend is a U-shaped curve, up to about the mid-1920s, as predicted by Slade (1982), but with a downward trend thereafter. The downward trend in real coal prices is marked since about the start of the Great Depression, with a steady negative slope of about -1.3% in annual terms up to about 1972, and about -0.5% afterwards. The real oil price trend also has a U shape: downward until World War II and then upward at a rate of roughly 2% per year thereafter. Note that the trends of both series change direction more than once, in contrast to the predictions of Slade's

¹⁰ Appendices C and D, which are available from the authors on request, provide supportive analysis of coal and oil price series: (i) unit root tests (which inform the choice of parameters in the ACF filter's detrending method), (ii) structural break tests, and (iii) verification that the identity between the nominal and real prices of coal holds for the various cyclical components.

theoretical model and empirical results.

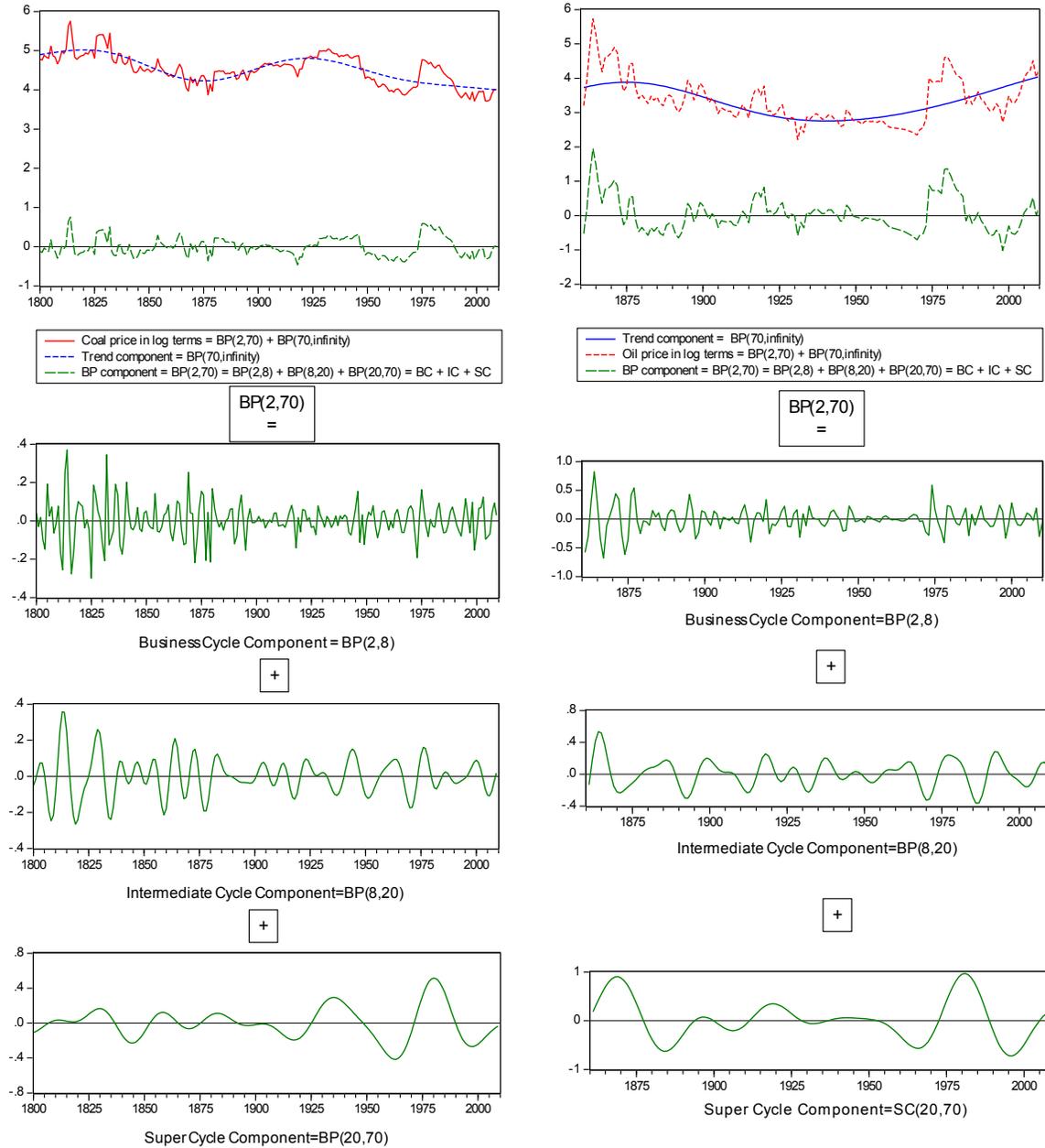


Figure 4: Trend and cycles in real coal (left panel) and oil (right panel) prices. All the components are in log terms.

Figure 5 shows the SCs for both the nominal and real price of coal and oil using the U.S. CPI as a deflator. The units on the vertical axis represent percentage deviations from trend. For example, $+0.20$ indicates a price 20% above the long-term trend. We can make two major observations about this figure. First, the amplitude at the peak of the SCs is generally higher

than the amplitude at the trough. The model of structural transformation in Cuddington and Zellou (2012) implies this asymmetry in the SC. Second, the magnitudes of the peaks in SCs have been gradually increasing from about 20% above trend in 1830 to about 50% in 1981.

Finally, Table 3 displays the correlation coefficient matrix for these four series. The SCs using the nominal and corresponding real series are quite similar, with a correlation coefficient of 0.78 for coal. This suggests that the SCs in real coal prices do not merely reflect movements in the price deflator.

Table 3: Super cycles in nominal and real coal prices: correlation matrix on the magnitude of the SCs between 1800-2010.

| Covariance Analysis: Ordinary | | | | |
|--|------------------------|---------------------|-----------------------|--------------------|
| Date: 04/03/12 Time: 13:47 | | | | |
| Sample: 1800 2010 | | | | |
| Included observations: 211 | | | | |
| Pairwise samples (pairwise missing deletion) | | | | |
| Correlation Probability | SC nominal coal prices | SC real coal prices | SC nominal oil prices | SC real oil prices |
| SC nominal coal prices | 1.00 ---- | | | |
| SC real coal prices | 0.78 0.00 | 1.00 ---- | | |
| SC nominal oil prices | 0.77 0.00 | 0.43 0.00 | 1.00 ---- | |
| SC real oil prices | 0.70 0.00 | 0.51 0.00 | 0.96 0.00 | 1.00 ---- |

The SCs for coal prices shown in Figure 5 average 38 years from trough to trough. Four SCs and two ambiguous periods are identified for coal: SC1: 18??-1845; ambiguous period 1: 1845-1871; ambiguous period 2: 1871-1918; SC2: 1918-1963; SC3: 1963-1998; SC4: 1998-20?? Low amplitudes in the SCs characterize the two ambiguous periods. The SCs over the past two centuries roughly match the different episodes of industrialization and urbanization in Western Europe, in the Western Offshoots (North America, Australia and New Zealand), in Europe again

following the reconstruction after World War II, in South-East Asia and finally in the BRIC¹¹ countries.

There appear to be three obvious SCs in oil prices, the first one between 1861 and 1884, and the last two between 1966-1996 and 1996 to-date. The period 1884-1966 is harder to interpret, due to the particular nature of the market during this period, and has been aggregated into an uncertain period. See the summary table with the correlation matrix for the expansion and contraction phases of the SCs for the different commodities (Table 4), based on data from Figure 6. Figure 7 shows the SCs for coal, oil and metals and the 30-year moving correlation between the SCs in oil and coal prices. Over the 148 year period of overlap (1861-2009) the correlation coefficient between these SCs starts low (or negative) but becomes much higher after World War II, as Figure 6 shows.

Table 4: Correlation between the SC expansion/contraction dummies (1/-1) for oil, coal and metals. See Figure 6 with the display of the expansion and contraction phases used in this correlation matrix.

Covariance Analysis: Ordinary
 Date: 04/04/12 Time: 15:28
 Sample: 1800 2010
 Included observations: 211
 Pairwise samples (pairwise missing deletion)

| Correlation Probability | OIL | COAL | METALS |
|-------------------------|--------------|--------------|--------------|
| OIL | 1.00 ---- | | |
| COAL | 0.91 0.00 | 1.00 ---- | |
| METALS | 0.86 0.00 | 0.16 0.14 | 1.00 ---- |

¹¹ The BRIC countries represent Brazil, Russia, India and China. The original acronym, BRICS, was invented in 2001 by Jim O’Neill, an economist at Goldman Sachs, and it includes South-Africa.

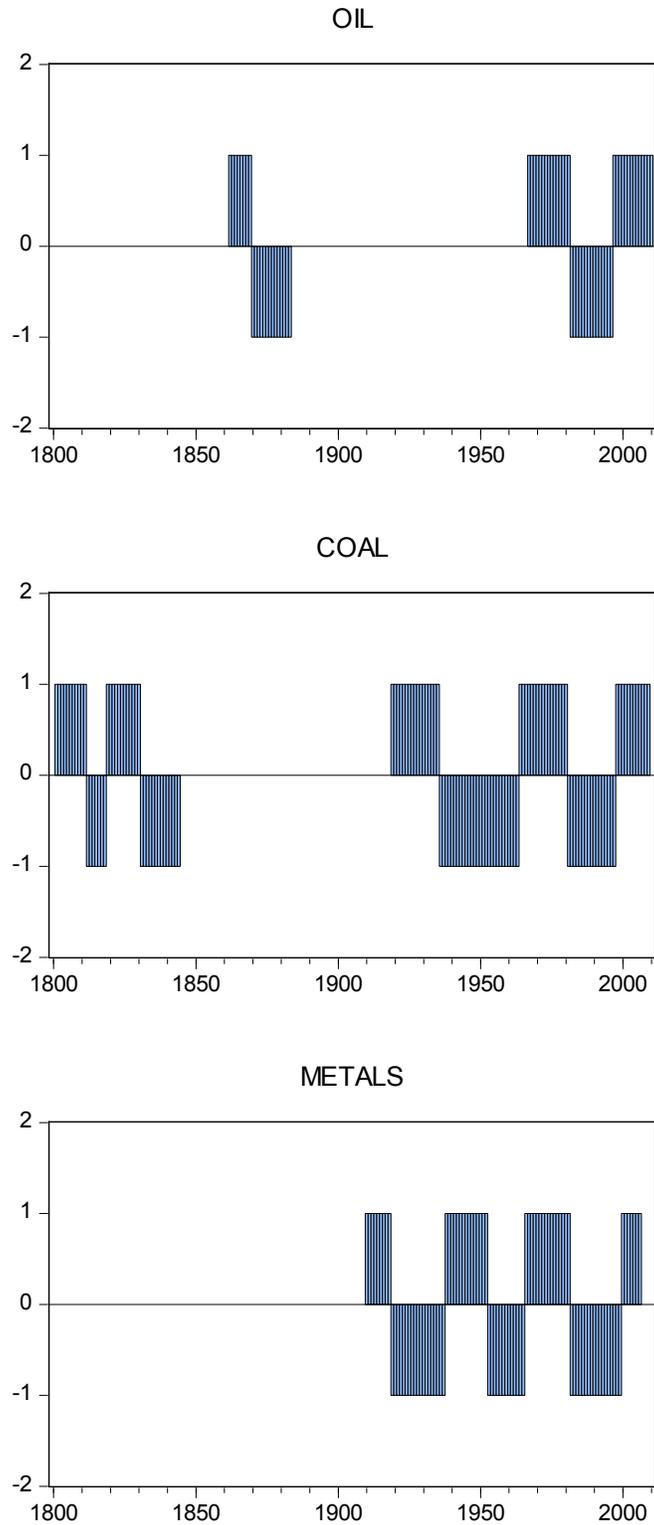


Figure 5: Dummies for the expansion and contraction phases in the super cycles for coal, oil and metals real prices over 1800-2010. The expansion phases are represented with a value of 1 and the contraction phases with a value of -1.

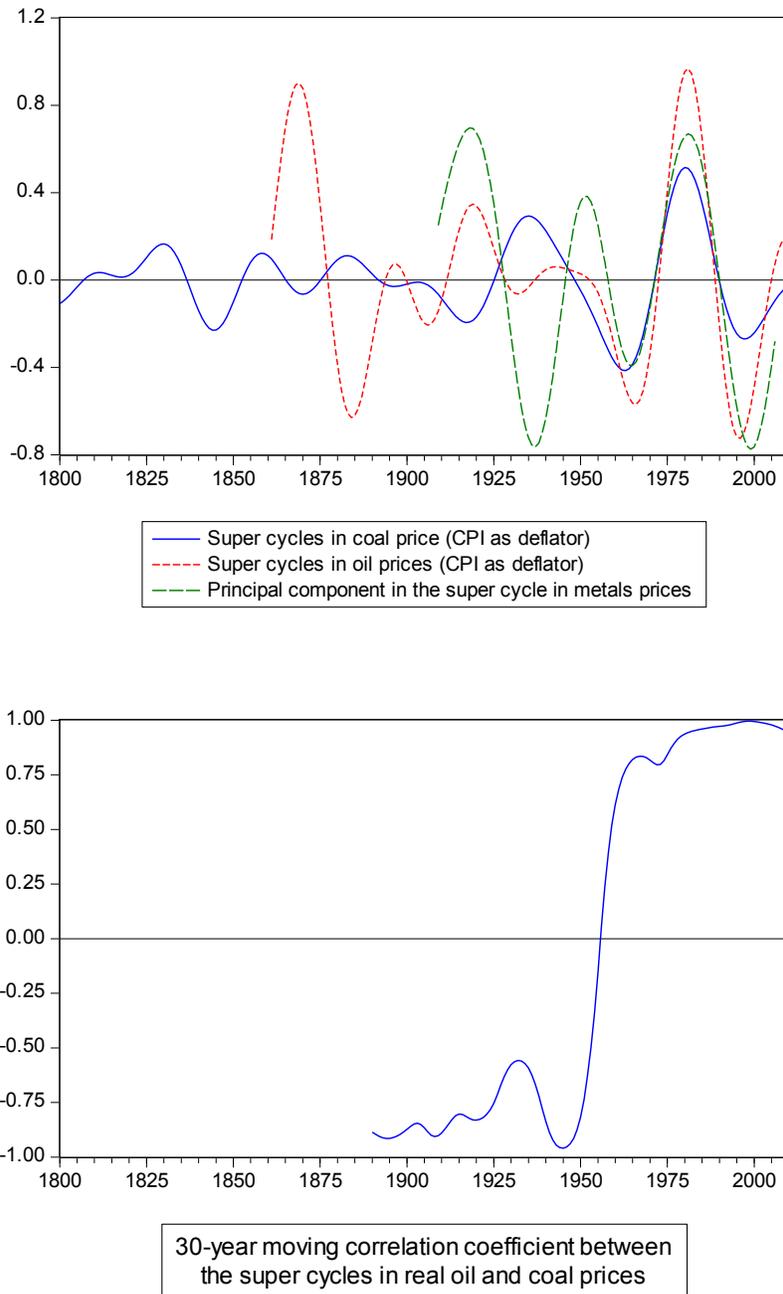


Figure 6: Super cycles for coal, oil and metals real prices over 1800-2010 (top panel). Correlation coefficient between the super cycles of oil and coal over the overlapping period 1861-2009 using a 30-year moving correlation statistic (bottom panel). The correlation between the coal and oil SC component is strongly positive (above 0.90) over the past 40 years, but is *negative* in the pre-WWII period.

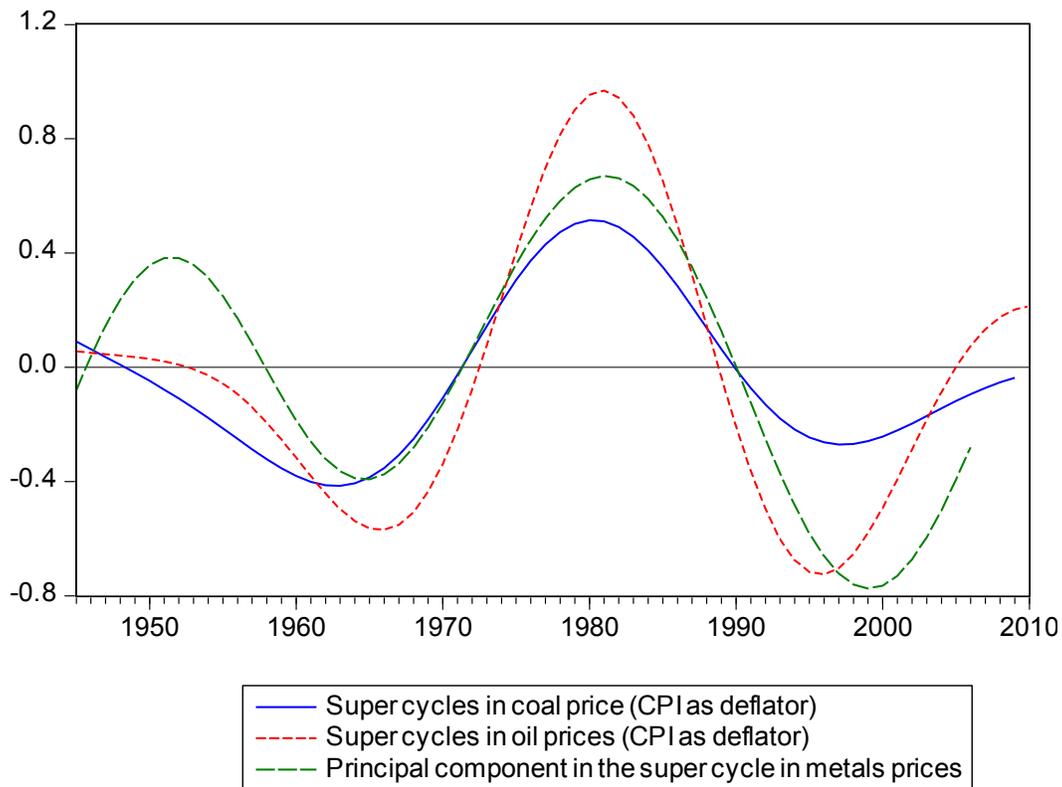


Figure 7: Super cycles in oil, coal and metals prices: 1945 2010. The correlation between the energy commodities and metals is stronger after WWII.

V. Conclusions

This paper uses the band-pass filter approach of Cuddington and Jerrett (2008) to: (i) study long-term trends in crude oil and coal prices and (ii) to search for evidence of super cycles in these energy commodity prices. We find that long-term trends have varied over time, with real coal prices trending downward and crude oil trending upward in the post World War II period. Indeed, real crude oil prices have increased at an average rate of 2.0% over this period. This suggests that the ongoing tug-of-war between depletion, exploration and technological change is playing out quite differently for these two energy commodities. Long-term trends for crude oil suggest that increasing economic scarcity is indeed an issue. For coal, however, this

does not seem to be the case, perhaps due to fuel substitution in electric power generation, increasingly stringent environmental regulations and abundant reserves.

Our empirical search found evidence of super cycles in both coal and oil prices in the post-World War II period, but not in the pre-WWII period. By applying the asymmetric Christiano-Fitzgerald band-pass filter, four SCs for coal were found: SC1: 18??-1845; SC2: 1918-1963; SC3: 1963-1998; SC4: 1998-ongoing. For crude oil, three SCs were identified: SC1: 1861-1884; SC2: 1966-1996; SC3: 1996-ongoing. These SCs correspond, at least during the post-WWII period, to episodes of industrialization and urbanization through history. The absence of super cycle behavior in crude oil prices in the pre-WWII period is not too surprising. After all, crude oil was not a primary energy source for fueling earlier industrialization and urbanization episodes. Recall from Fig.2 the low crude oil share in total U.S. energy consumption even through the inter-war period, coal being the dominant fuel source.

Most analysts believe that oil and coal will remain as the two major sources of energy for the foreseeable future. Such forecasts, of course, depend on expected long-term price trends, changing environmental regulations, technological developments (e.g. in shale oil and gas production), and the boom in U.S. natural gas production (resulting from the development of fracking and other technologies). These supply-side considerations will interact in complicated ways with the surges in global demands associated with economic development in China and other large LDCs to determine the duration of the current super cycle expansion in crude oil and coal markets.

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APPENDIX A: A BRIEF HISTORY OF COAL IN THE US¹²

- 1000 A.D. Hopi Indians, living in what is now Arizona, use coal to bake pottery made from clay.
- 1673-74 Louis Jolliet and Father Jacques Marquette discover “charbon de terra” (coal) at a point on the Illinois River during their expedition on the Mississippi River.
- 1701 Coal is found by Huguenot settlers at Manakin on the James River, near what is now Richmond, Virginia.
- 1748 The first recorded commercial U.S. coal production from mines in the Manakin area.
- 1762 Coal is used to manufacture, shot, shell, and other war material during Revolutionary War.
- 1816 Baltimore, Maryland becomes the first city to light streets with gas made from coal.
- 1830 The first commercially practical American-built locomotive, the Tom Thumb, is manufactured. Early locomotives that burned wood were quickly modified to use coal almost entirely.
- 1839 The steam shovel is invented and eventually becomes instrumental in mechanizing surface coal mining.
- 1848 The first coal miners' union is formed in Schuylkill County, PA.
- 1866 Surface mining, then called “strip” mining, begins near Danville, Illinois. Horse-drawn plows and scrapers are used to remove overburden so the coal can be dug and hauled away in wheelbarrows and carts.
- 1875 Coke replaces charcoal as the chief fuel for iron blast furnaces.
- 1890 The United Mine Workers of America is formed.
- 1896 Steel timbering is used for the first time at the shaft mine of the Spring Valley Coal Co., where 400 feet of openings are timbered with 15-inch beams.
- 1901 General Electric Co. builds the first alternating current power plant at Ehrenfeld, Pennsylvania, for Webster Coal and Coke Co., to eliminate inherent difficulties in long-distance direct-current transmission.

¹² Chronology taken from the American Coal foundation:
http://www.teachcoal.org/lessonplans/pdf/coal_timeline.pdf

- 1912 The first self-contained breathing apparatus for mine rescue operations is used.
- 1930 Molded, protective helmets for miners are introduced.
- 1937 The shuttle car is invented.
- 1961 Coal becomes the major fuel used by electric utilities to generate electricity.
- 1973 Oil embargo by the Organization of Petroleum Exporting Companies (OPEC) focuses attention on the energy crisis and results in increased demand for U.S. coal.
- 1977 Surface Mining Control and Reclamation Act (SMCRA) passed.
- 1986 Clean Coal Technology Act passed.
- 1990 U.S. coal production tops one billion tons in a single year for the first time.
- 1995 The National Coal Association and the American Mining Congress merge into the National Mining Association, representing coal and minerals-producing companies.
- 1996 Energy Policy Act goes into effect, opening electric utility markets for competition between fuel providers.
- 2002 Coal mining companies reclaimed two million acre of mined land.
- 2005 Congress passes and President signs into law the Energy Policy Act of 2005 that promotes increased use of coal through clean coal technologies.

APPENDIX B: A BRIEF HISTORY OF OIL

Hamilton (2011) and Yergin (1991) provide detailed descriptions of the history of the oil market.

The brief chronology provided here relies mainly on these two sources.

- 1859-1899: Let there be light
 - 1862-1864: the first oil shock with the rapid drop in oil prices
 - 1865-1899: evolution of the industry: still drop in price
 - Hamilton does not see agree with the interpretation of Dvir and Rogoff on the similarities in the behavior of oil prices, in terms of restriction of access to the excess oil supply, between the 19th century and the last quarter of the 20th century. Indeed, Hamilton argues that oil did not have as much economic importance at the end of the 19th century compared to the end of the 20th century. The share of oil in GNP is much smaller in the 19th century compared to the last quarter of the 20th (0.4% of 1900 GNP compared to 4.8% of 2008 GDP).
- 1900-1945: Power and transportation
 - The west coast gasoline famine of 1920
 - The great depression and state regulations. These state regulations focused on restricting production, which allowed a better management of the East Texas Oil Field compared to the early fields in Pennsylvania (see Figures 3.1 and 3.5 of the Chapter 3).
- 1946-1972: The early postwar era.
 - State regulation

- 1947-1948: Postwar dislocations: increase in the price of oil due to acceleration in the use of vehicles.
- 1952-1953: supply disruptions and the Korean conflict.
- 1956-1957: Suez Crisis
- 1969-1970: Modest price increases.
- 1973-1996: The age of OPEC.
 - 1973-1974: OPEC Embargo.
 - 1978-1979: Iranian revolution.
 - 1980-1981: Iran-Iraq War.
 - 1981-1986: The great price collapse.
 - 1990-1991: First Persian Gulf War.
- 1997-2010: A new industrial age.
 - 1997-1998: East Asian Crisis.
 - 1999-2000: Resumed growth.
 - 2003: Venezuelan unrest and the second Persian Gulf War.
 - 2007-2008: Growing demand and stagnant supply.

Zellou and Cuddington. 2012. Trends and Super Cycles in Crude Oil and Coal Prices.**
Appendices C and D -- **Not for publication/Available from the authors on Request**

APPENDIX C: ECONOMETRIC ANALYSIS OF THE BP PRICE SERIES

Comparison of the WTI and Brent Nominal Prices.

Figure C.1 displays the nominal price of oil (on natural logarithm scale). In order to assess if the choice of benchmark (e.g., Brent, WTI, Arabian light) has an effect on the analysis, we compare WTI and Brent over the 1986-2010 period. Figure C.2 gives the price of oil in log scale using WTI. Figure C.3 shows both prices (Brent and WTI) in logs as well as the difference. There is no significant difference between WTI and the Brent prices. The correlation coefficient for the trending series between the nominal price of Brent and WTI is .999 over that period. Hence, the results presented in this chapter will be using the BP series only, even though we computed the SCs in both cases using Brent and WTI.

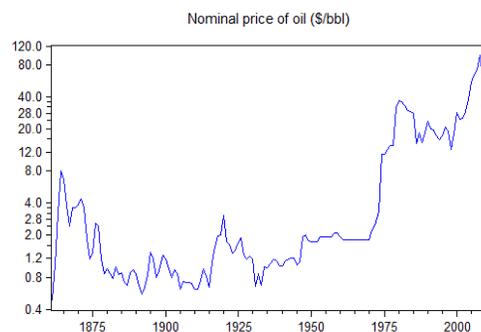


Figure C.1: Nominal price of oil in level on a log scale [Source BP statistical review (BP 2011)].

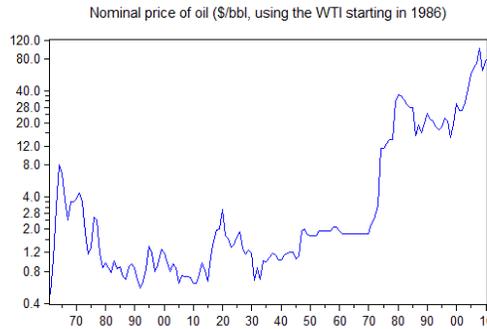


Figure C.2: Nominal price of oil in level on a log scale using the WTI starting in 1986.

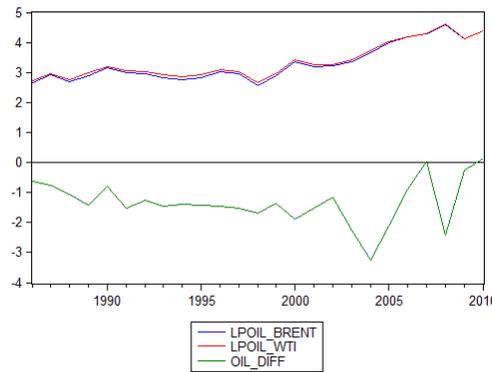


Figure C.3: Nominal price of the WTI and Brent in logs over the 1986-2010 period and the difference.

Unit Root Tests.

As described earlier, the oil series is composed of three different prices, with the US crude starting in 1861, the Arabian Light price used after 1944 and the Brent price starting in 1986. We want to investigate whether there is a presence of a structural break at these splicing points (at 1986 and 1944).

First, we checked the presence of a unit root on the log of the real price of oil. The Phillips-Perron test statistic in Table C.1 shows that the log of the real price of oil is integrated of degree one ($I(1)$). This means that the time series needs to be differentiated once to be stationary. Failing to do so will lead to spurious regressions. The Philips-Perron unit root test is preferred to the Dickey-Fuller test in the case of time varying volatility,

which is the case here. The Philips-Perron unit root test uses robust standard error while the Dickey-Fuller does not. The null hypothesis of a second unit root is rejected. The lag length selection criteria show that two lags are necessary based on the sequential modified likelihood ratio (LR) test statistic and the Akaike information criterion (AIC) (Table C.2). Hence, we ran the following univariate model:

$$DLPRoil_BP_cpi_t = \alpha + \beta_1 DLPRoil_BP_cpi_{t-1} + DLPRoil_BP_cpi_{t-2} + e_t \quad (C-1)$$

Structural Breaks.

When using the univariate equation specified above to test for the presence of structural breaks at the splicing date, we find that there are no structural breaks (Table C.3, Figure C.4 and Table C.4). We also performed a Chow breakpoint test at several other dates around these splicing dates, in 1945, 1946, 1984 and 1985, and they all rejected the presence of a structural break.

Table C.1: Unit root test on the real price of oil. The series is I(1).

Null Hypothesis: D(LPROIL_BRENT_CPI) has a unit root
 Exogenous: None
 Bandwidth: 23 (Newey-West automatic) using Bartlett kernel

| | Adj. t-Stat | Prob.* |
|--------------------------------|-------------|--------|
| Phillips-Perron test statistic | -12.27283 | 0.0000 |
| Test critical values: | | |
| 1% level | -2.580681 | |
| 5% level | -1.942996 | |
| 10% level | -1.615279 | |

*Mackinnon (1996) one-sided p-values.

| | |
|--|----------|
| Residual variance (no correction) | 0.081471 |
| HAC corrected variance (Bartlett kernel) | 0.023572 |

Phillips-Perron Test Equation
 Dependent Variable: D(LPROIL_BRENT_CPI,2)
 Method: Least Squares
 Date: 02/02/11 Time: 16:47
 Sample (adjusted): 1863 2010
 Included observations: 148 after adjustments

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|--------------------------|-------------|------------|-------------|--------|
| D(LPROIL_BRENT_CPI(-...) | -0.865970 | 0.080161 | -10.80285 | 0.0000 |

| | | | |
|--------------------|-----------|-----------------------|-----------|
| R-squared | 0.442509 | Mean dependent var | -0.003365 |
| Adjusted R-squared | 0.442509 | S.D. dependent var | 0.383578 |
| S.E. of regression | 0.286400 | Akaike info criterion | 0.343877 |
| Sum squared resid | 12.05764 | Schwarz criterion | 0.364128 |
| Log likelihood | -24.44690 | Hannan-Quinn criter. | 0.352105 |
| Durbin-Watson stat | 1.981468 | | |

Table C.2: Lag length selection for the real price of oil.

VAR Lag Order Selection Criteria
 Endogenous variables: DLPROIL_BRENT_CPI
 Exogenous variables: C
 Date: 02/03/11 Time: 12:47
 Sample: 1861 2010
 Included observations: 141

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|-----|-----------|-----------|-----------|-----------|-----------|-----------|
| 0 | -11.05024 | NA | 0.069464 | 0.170925 | 0.191839* | 0.179424* |
| 1 | -11.03633 | 0.027431 | 0.070442 | 0.184912 | 0.226739 | 0.201909 |
| 2 | -8.860494 | 4.259076* | 0.069277* | 0.168234* | 0.230974 | 0.193729 |
| 3 | -8.020700 | 1.631939 | 0.069436 | 0.170506 | 0.254159 | 0.204500 |
| 4 | -8.009230 | 0.022127 | 0.070417 | 0.184528 | 0.289094 | 0.227020 |
| 5 | -7.535710 | 0.906741 | 0.070946 | 0.191996 | 0.317475 | 0.242986 |
| 6 | -6.994343 | 1.028982 | 0.071412 | 0.198501 | 0.344894 | 0.257990 |
| 7 | -6.760999 | 0.440208 | 0.072195 | 0.209376 | 0.376681 | 0.277363 |
| 8 | -4.773437 | 3.721394 | 0.071195 | 0.195368 | 0.383587 | 0.271853 |

* indicates lag order selected by the criterion
 LR: sequential modified LR test statistic (each test at 5% level)
 FPE: Final prediction error
 AIC: Akaike information criterion
 SC: Schwarz information criterion
 HQ: Hannan-Quinn information criterion

Table C.3: Univariate regression of the real price of oil using two lags.

| Dependent Variable: DLPROIL_BRENT_CPI | | | | |
|--|-------------|-----------------------|-------------|--------|
| Method: Least Squares | | | | |
| Date: 02/03/11 Time: 13:05 | | | | |
| Sample (adjusted): 1864 2010 | | | | |
| Included observations: 147 after adjustments | | | | |
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
| C | -0.002942 | 0.022583 | -0.130291 | 0.8965 |
| DLPROIL_BRENT_CPI(-1) | 0.108051 | 0.079104 | 1.365926 | 0.1741 |
| DLPROIL_BRENT_CPI(-2) | -0.185775 | 0.078187 | -2.376048 | 0.0188 |
| R-squared | 0.044469 | Mean dependent var | -0.004525 | |
| Adjusted R-squared | 0.031198 | S.D. dependent var | 0.278042 | |
| S.E. of regression | 0.273671 | Akaike info criterion | 0.266414 | |
| Sum squared resid | 10.78497 | Schwarz criterion | 0.327443 | |
| Log likelihood | -16.58143 | Hannan-Quinn criter. | 0.291211 | |
| F-statistic | 3.350756 | Durbin-Watson stat | 2.137098 | |
| Prob(F-statistic) | 0.037812 | | | |

Table C.4: Chow test to test for structural breaks at the splicing points of the oil price series in 1944 and 1986. There are no structural breaks.

| Chow Breakpoint Test: 1944 1986 | | | |
|---|----------|---------------------|--------|
| Null Hypothesis: No breaks at specified breakpoints | | | |
| Varying regressors: All equation variables | | | |
| Equation Sample: 1864 2010 | | | |
| F-statistic | 0.819216 | Prob. F(6,138) | 0.5568 |
| Log likelihood ratio | 5.144767 | Prob. Chi-Square(6) | 0.5254 |
| Wald Statistic | 4.915293 | Prob. Chi-Square(6) | 0.5547 |

| Date: 02/03/11 Time: 13:06 | | | | | | |
|----------------------------|---------------------|----|--------|--------|--------|-------|
| Sample: 1864 2010 | | | | | | |
| Included observations: 147 | | | | | | |
| Autocorrelation | Partial Correlation | AC | PAC | Q-Stat | Prob | |
| | | 1 | -0.106 | -0.106 | 1.6818 | 0.195 |
| | | 2 | -0.016 | -0.027 | 1.7197 | 0.423 |
| | | 3 | -0.106 | -0.112 | 3.4232 | 0.331 |
| | | 4 | 0.030 | 0.005 | 3.5574 | 0.469 |
| | | 5 | 0.077 | 0.077 | 4.4653 | 0.485 |
| | | 6 | 0.105 | 0.115 | 6.1843 | 0.403 |
| | | 7 | -0.026 | 0.008 | 6.2915 | 0.506 |
| | | 8 | 0.080 | 0.103 | 7.2879 | 0.506 |
| | | 9 | -0.179 | -0.147 | 12.362 | 0.194 |
| | | 10 | -0.045 | -0.097 | 12.681 | 0.242 |
| | | 11 | -0.064 | -0.100 | 13.335 | 0.272 |
| | | 12 | 0.039 | -0.033 | 13.586 | 0.328 |

Figure C.4: Correlogram of the residual corresponding to the univariate regression of the real oil price above (in first difference of the log term).

APPENDIX D: ECONOMETRIC ANALYSIS OF THE COAL PRICE SERIES

Unit Root Tests

The presence of a unit root on the log of the real price of coal is tested. The Phillips-Perron test statistic in Table D.1 shows that the log of the real price of coal is integrated of degree one (I(1)). The null hypothesis of a second unit root is therefore rejected. The lag length selection criteria show that three lags are necessary based on the sequential modified likelihood ratio (LR) test statistic and the Akaike information criterion (AIC) (Table D.2). Hence, it is appropriate to run a univariate model with three lags:

$$DLPRcoal_cpi_t = \alpha + \sum_{i=1}^3 \beta_i DLPRcoal_cpi_{t-i} + e_t \quad (D-1)$$

Structural Break

In the case of coal, there are no splicing dates in its price. A Quandt-Andrews breakpoint test is performed in order to test for the presence of a structural break at an unknown date. The result of the test in Table D.3 shows that there is no structural break in the coal series.

Table D.1: Unit root test on the log of the real price of coal. The log of the real price of oil is I(1), meaning the price series has one unit root. There is no second unit root.

| Phillips-Perron Unit Root Test on LPRCOAL_CPI | | | | |
|---|-------------|-----------------------|-------------|-----------|
| Null Hypothesis: LPRCOAL_CPI has a unit root | | | | |
| Exogenous: Constant | | | | |
| Bandwidth: 7 (Newey-West automatic) using Bartlett kernel | | | | |
| | | | Adj. t-Stat | Prob.* |
| Phillips-Perron test statistic | | | -2.399627 | 0.1431 |
| Test critical values: | | | | |
| | 1% level | | -3.461630 | |
| | 5% level | | -2.875195 | |
| | 10% level | | -2.574125 | |
| *Mackinnon (1996) one-sided p-values. | | | | |
| Residual variance (no correction) | | | | 0.021463 |
| HAC corrected variance (Bartlett kernel) | | | | 0.017719 |
| Phillips-Perron Test Equation | | | | |
| Dependent Variable: D(LPRCOAL_CPI) | | | | |
| Method: Least Squares | | | | |
| Date: 12/14/11 Time: 08:11 | | | | |
| Sample (adjusted): 1801 2009 | | | | |
| Included observations: 209 after adjustments | | | | |
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
| LPRCOAL_CPI(-1) | -0.068423 | 0.025831 | -2.648910 | 0.0087 |
| C | 0.305542 | 0.117183 | 2.607403 | 0.0098 |
| R-squared | 0.032786 | Mean dependent var | | -0.003690 |
| Adjusted R-squared | 0.028113 | S.D. dependent var | | 0.149322 |
| S.E. of regression | 0.147208 | Akaike info criterion | | -0.984416 |
| Sum squared resid | 4.485735 | Schwarz criterion | | -0.952432 |
| Log likelihood | 104.8715 | Hannan-Quinn criter. | | -0.971485 |
| F-statistic | 7.016724 | Durbin-Watson stat | | 2.021837 |
| Prob(F-statistic) | 0.008698 | | | |

Table D.2: Lag selection criteria for coal. The lag length selection criteria performed on the first difference of the real price of coal shows that three lags are necessary based on the sequential modified likelihood ratio (LR) test statistic and the Akaike information criterion (AIC).

| VAR Lag Order Selection Criteria | | | | | | | |
|---|----------|-----------|-----------|------------|------------|------------|--|
| Endogenous variables: D(LPRCOAL_CPI) | | | | | | | |
| Exogenous variables: C | | | | | | | |
| Date: 12/14/11 Time: 08:17 | | | | | | | |
| Sample: 1800 2010 | | | | | | | |
| Included observations: 201 | | | | | | | |
| Lag | LogL | LR | FPE | AIC | SC | HQ | |
| 0 | 98.09015 | NA | 0.022283 | -0.960071 | -0.949637* | -0.959421* | |
| 1 | 98.19298 | 0.203604 | 0.022482 | -0.957144 | -0.924275 | -0.943844 | |
| 2 | 98.89663 | 1.386296 | 0.022549 | -0.954195 | -0.904892 | -0.934245 | |
| 3 | 102.8959 | 7.839445* | 0.021886* | -0.984039* | -0.918302 | -0.957439 | |
| 4 | 102.9471 | 0.099848 | 0.022094 | -0.974598 | -0.892427 | -0.941348 | |
| 5 | 103.2375 | 0.563422 | 0.022250 | -0.967537 | -0.868931 | -0.927637 | |
| 6 | 103.7476 | 0.984575 | 0.022359 | -0.962662 | -0.847622 | -0.916112 | |
| 7 | 104.9295 | 2.269742 | 0.022319 | -0.964472 | -0.832998 | -0.911272 | |
| 8 | 105.0779 | 0.283521 | 0.022510 | -0.955999 | -0.808090 | -0.896148 | |
| * indicates lag order selected by the criterion | | | | | | | |
| LR: sequential modified LR test statistic (each test at 5% level) | | | | | | | |
| FPE: Final prediction error | | | | | | | |
| AIC: Akaike information criterion | | | | | | | |
| SC: Schwarz information criterion | | | | | | | |
| HQ: Hannan-Quinn information criterion | | | | | | | |

Table D.3: Quandt-Andrews breakpoint test at an unknown date on the coal series. The result of the test shows that there is no structural break on the coal series.

| Quandt-Andrews unknown breakpoint test | | |
|---|----------|--------|
| Null Hypothesis: No breakpoints within 15% trimmed data | | |
| Varying regressors: All equation variables | | |
| Equation Sample: 1804 2009 | | |
| Test Sample: 1835 1979 | | |
| Number of breaks compared: 145 | | |
| Statistic | Value | Prob. |
| Maximum LR F-statistic (1899) | 1.825755 | 0.6916 |
| Maximum Wald F-statistic (1920) | 9.142540 | 0.4687 |
| Exp LR F-statistic | 0.689882 | 0.3673 |
| Exp Wald F-statistic | 3.491893 | 0.2086 |
| Ave LR F-statistic | 1.365553 | 0.1846 |
| Ave Wald F-statistic | 6.336956 | 0.1084 |
| Note: probabilities calculated using Hansen's (1997) method | | |