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Re-examining the Existence of Cycles and Co-movements in the Prices of Food Commodities and Agricultural Raw Materials Using Wavelet Analysis

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CRANFIELD UNIVERSITY

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This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science

ABSTRACT

Despite a raft of government reports forecasting that real prices of food commodities and agricultural raw materials will follow a continuous upward trend in the short to medium term, most previous academic studies show that commodity prices move in cycles (trough-peak-trough) and the prices of seemingly unrelated commodities move together (co-movement). However, the dynamics of cycles and co-movements are poorly understood. Without understanding commodity price dynamics, it is unlikely that government strategies for food, fuel and material security will succeed.

In this context, this study applies Wavelet analysis (time-scale decomposition) to develop knowledge of cycles in the prices of and co-movements of 22 investigated commodities and US Gross Domestic Product, crude oil price and gold price. This study is novel in providing the first application (to the author's knowledge) of Wavelet analysis to the study of agricultural commodities.

The results confirm that the prices of the majority of investigated commodities experienced the majority of significant cycles in the mid 1970s and 9 commodities post 2004 as well. Almost no significant cycles occurred in the rest of the time series. The cyclical behaviour is explained predominantly by prices of crude oil and gold, which led co-movements in the price of food commodities and agricultural raw materials. In particular commodity price cycles were led by the crude oil price in 16 cases, which is important for further research. The results support previous studies that find commodity price cycles and suggest that governmental strategies for food security should be based on volatile cycles rather than a continuous uni-directional movement in food commodity and agricultural raw material prices.

Keywords:

Commodity, Price, Cycle, Co-movement, Wavelet Analysis, Continuous Wavelet Transform, Cross Wavelet Transform, Wavelet Coherence

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Re-examining the Existence of Cycles and Co-movements in the Prices of Food Commodities and Agricultural Raw Materials Using Wavelet Analysis

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Abstract

Despite a raft of government reports forecasting that real prices of food commodities and agricultural raw materials will follow a continuous upward trend in the short to medium term, most previous academic studies show that commodity prices move in cycles (trough-peak-trough) and the prices of seemingly unrelated commodities move together (co-movement). However, the dynamics of cycles and co-movements are poorly understood. Without understanding commodity price dynamics, it is unlikely that government strategies for food, fuel and material security will succeed.

In this context, this study applies Wavelet analysis (time-scale decomposition) to develop knowledge of cycles in the prices of and co-movements of 22 investigated commodities and US Gross Domestic Product, crude oil price and gold price. This study is novel in providing the first application (to the author's knowledge) of Wavelet analysis to the study of agricultural commodities.

The results confirm that the prices of the majority of investigated commodities experienced the majority of significant cycles in the mid 1970s and 9 commodities post 2004 as well. Almost no significant cycles occurred in the rest of the time series. The cyclical behaviour is explained predominantly by prices of crude oil and gold, which led co-movements in the price of food commodities and agricultural raw materials. In particular commodity price cycles were led by the crude oil price in 16 cases, which is important for further research. The results support previous studies that find commodity price cycles and suggest that governmental strategies for food security should be based on volatile cycles rather than a continuous uni-directional movement in food commodity and agricultural raw material prices.

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1 INTRODUCTION

The stability of commodity prices is important to all economies regardless of their state of development (Dick et al., 1983; Cristini, 1995). Developing countries tend to be relatively specialised in production of commodities and hence, commodity price fluctuations often affect the poorest. However, commodity price volatility also impacts more affluent nations, affecting consumption and production levels, unemployment rates, wages, interest rates and a nation's balance of payments (Myers, 2006; Kannapiran, 2000; Moosa, 1998; Cristini 1995). Thus, with food prices expected to increase over the long-term, there may be undesirable economic consequences for a large number of countries.

However, evidence that the long-term real prices of food commodities and agricultural raw materials are increasing, reflecting increasing scarcity, is mixed (Ghoshray, 2011; Kellard and Wohar, 2006; Cashin *et al*. 2002; Grilli and Yang 1988; Prebisch, 1950; Singer, 1950). Furthermore, there is a mixed evidence of the short-term fluctuations as well (Power and Turvey, 2010; Siqueira Jr. *et al*., 2010; Chatrath *et al*., 2002; Voituriez, 2001). Previous studies had mixed results as researchers employed various methods and interpreted results differently. As cycle identification is very difficult, mainly imperfect methods, which are further discussed in section 3, caused this disunity.

This paper aims to re-assess cycles in and co-movements of food commodity and agricultural raw material prices from 1961 to 2010 using Wavelet analysis, which to the author's knowledge, has not been used for this purpose before. The main objectives of this paper are to:

1. Test for cycles in food commodity and agricultural raw material prices
2. Test for co-movements of food commodity and agricultural raw materials prices and
    a. US Gross Domestic Product Growth
    b. Crude Oil Price
    c. Gold Price

3. Identify the main drivers of these cycles and co-movements
4. Identify fundamental policy implications

This paper continues by section 2 which undertakes a review of the literature. Section 3 describes Wavelet analysis and the model constructed to meet the study objectives. Section 4 presents the results, which are discussed in section 5, while sections 6 summarises the main findings and makes suggestions for further research.

2 LITERATURE REVIEW

2.1 Trends in Commodity Prices

The behaviour of commodity prices, particularly over the long-term, is imperfectly understood. Accordingly competing hypotheses exist. The Prebisch-Singer hypothesis, states that commodity prices will continuously decrease relative to prices of manufactured products.

In their seminal paper Grilli and Yang (1988) tested the Prebisch-Singer hypothesis over the period from 1900 to 1986. They found that the relative price of all primary commodities lost 0.5% of its value to manufactures per annum. Excluding energy commodities, primary commodities lost 0.6% of their value per annum. However, within their research they found that agricultural commodities, such as cereals had smaller declines than an average of all primary commodities and the relative prices of beverages even increased over the period. In contrast, the relative prices of agricultural raw materials were decreasing as the average of all primary commodities. Thus, Grilli and Yang (1988) found no evidence to reject the Prebisch-Singer hypothesis completely, only for specific commodities.

Bleaney and Greenaway (1993) also tested the Prebisch-Singer hypothesis and found that the period of study had a crucial influence on the results. The period from 1925 to 1980 showed a minimal decline of primary commodities relative to manufactures, which conflicted with the study by Grilli and Yang (1988). However, since 1984, Bleaney and Greenaway (1993) results showed that the relative primary commodity prices had been decreasing and had stayed at lower relative levels than before 1981. Svedberg and Tilton (2006) analysed the development of copper prices over the period from 1870 to 2000. It was found that the real price of copper had declined over this period, but not significantly. However, Svedberg and Tilton (2006) concluded that there had been longer periods (20 years long) when prices were declining and increasing as well. These periods indicated cyclical behaviour. The similar findings (but for wider range of commodities) were provided by Ghoshray (2011) and Kellard and

Wohar (2006) as well. It weakened the Prebisch-Singer hypothesis of the long-term trend and suggested that commodity price movements are dominated by long-term and short-term cycles.

2.2 Cycles and Co-movements in Commodity Prices

Cycles and co-movements have long been recognised as stylized characteristics of commodity prices by some, but disputed by others (Nazlioglu, 2011; Wang *et al*., 2010; Lescaroux, 2009; Baffes, 2007; Cashin *et al*., 2002; Cristini, 1995). For instance, Cashin *et al*. (2002) analysed 36 commodity prices in the period between 1957 and 1999 and found cycles to be the dominant feature of commodity prices. Moreover, Cashin *et al*. (2002) found an asymmetry in cycles. It was detected that slumps in commodity prices tend to prevail for a longer period than price booms.

The prices of food commodities and agricultural raw materials display cyclical characteristics. Wang *et al*. (2010) emphasised the volatility of maize, rice, soybeans and wheat prices in China between 1997 and 2009. Such fluctuation provided a possibility to a cycle formation. They found that even though there had been more slumps than booms in the development of prices of these commodities, the average duration of slumps had been shorter than the average duration of booms. Maize fluctuated the most with 15 cycles, while wheat experienced only 6 cycles. Although all of these commodities experienced cyclical behaviour, it did not find any evidence of co-movements. The high number of cycles indicated that prices of maize, rice, soybeans, wheat and in fact all commodities were volatile in China and also on world markets.

Pindyck and Rotemberg (1990) provided evidence to support the hypothesis that the price of seemingly unrelated commodities move together. They studied prices of cocoa, copper, cotton, crude oil, gold, lumber and wheat. Correlations between monthly prices of these commodities were highly significant from 1960 to 1985. This co-movement may be explained by liquidity constraints (a wheat price slump decreases maize price as it decreases a value of speculators' long-term investments) or commodity market reactions to non-economic factors (subjective decisions of market participants – bubbles, terrorism, weather). Lescaroux (2009) analysed 51 commodities from 1980 to 2008 and found that there were only non-significant linkages between commodities themselves, a finding that was supported by Ai *et al*. (2006) and Deb *et al*. (1996).

Cashin *et al*. (1999) found no evidence for co-movements/correlation in commodities, which he considered as unrelated (cocoa, cotton and wheat). Instead they found that only prices of commodities which were coproduced, substitutes or complements had had a tendency to move together.

2.3 Commodity Prices and Crude Oil Price

Another reason for co-movements in commodity prices is the link between input and output prices. For instance, Ozkan *et al*. (2005) suggested that food commodity and agricultural raw material prices were positively correlated with input prices, such as crude oil. Nazlioglu (2011) found that food commodity prices of maize, soybeans and wheat could be predicted based on changes in the price of crude oil price. These linkages between agricultural commodity prices and the crude oil price are likely to be strengthened as plant derived Biofuels became an increasingly competitive substitute for crude oil products (Nazlioglu, 2011; Esmaeili and Shokoohi, 2011). Baek and Koo (2010) supported this hypothesis, finding a significant linkage between US food prices and energy prices over the period 1989 – 2008, as did Harri *et al*. (2009) who found that prices of cotton, maize and soybeans were linked to the crude oil price, but could not find any linkage between prices of wheat and crude oil. Baffes (2007) calculated the price transmission effects of changes in crude oil prices on other commodities (cross-price elasticities between agricultural commodities and crude oil – 0.17, beverages – 0.26, food – 0.18, cereals – 0.18, fats and oils 0.19).

Esmaeili and Shokoohi (2011) found that Biofuels production was considered as one of the latest factors which were causing an increase in food commodity prices. Beak and Koo (2010) also found a significant linkage between US food prices and energy prices between 1989 and 2008. They attributed this strong linkage to increasing Biofuels production. Harri *et al*. (2009) found that prices of cotton, maize and soybeans had been linked to the crude oil price.

Local food commodity prices do not necessary follow this pattern (Nazlioglu, 2011; Nazlioglu and Soytas, 2011). Nazlioglu and Soytas (2011) found no evidence to support the hypothesis that the national prices of cotton, maize, soybeans, sunflowers and wheat in Turkey followed short-term fluctuations of the price of crude oil. This result was confirmed by Mutuc *et al*. (2010) where the US price of cotton was investigated and almost no linkage to the crude oil price was found.

Baek and Koo (2010) provided different findings than Nazlioglu (2011). Beak and Koo (2010) found a significant linkage between US food prices and energy prices between 1989 and 2008. They attributed this strong linkage to Biofuels production as did Harri *et al*. (2009).

Commodity Prices and Economic Performance

Hua (1998) found a relationship between non-oil commodity prices (US$), economic activities and real exchange rate, as did Akram (2009) who emphasised that commodity prices had risen when real exchange rate of US$ had depreciated relative to other currencies and when US interest rates had fallen. Real exchange rate led commodity prices. Cashin *et al*. (2004) identified the co-movements of the real exchange rates of countries that had exported some particular commodity and the real price of that commodity. Even though it was unconfirmed for all of 58 investigated countries, there was some evidence of a long-term relationship between real exchange rates and real prices of commodities for 1/3 of investigated countries.

3 METHODOLOGY

The core of this research was to investigate relationships between agricultural commodity prices and other selected variables, which are specified in section 3.4. Based on the methods which had been formerly employed and contemporary research which had been undertaken (mainly Fourier analysis, identification of cycle durations, boom-slump method and consequent Brain-Shapiro test), Wavelet analysis was selected. The application of Wavelet analysis was novel as it had not been used to investigate food commodity and agricultural raw material prices before (to the author's knowledge). According to Moore and Grinsted (2003), it is an effective tool to decompose time series.

Wavelet analysis was the appropriate one for this research as it minimised disadvantages of Fourier analysis by enabling better time-scale decomposition of time series. Three functions of the Wavelet analysis were employed in this research, all calculated using Matlab R2010a (version: 7.10.0.499):

- Continuous Wavelet Transform (CWT)
- Cross Wavelet Transform (XWT)
- Wavelet Coherence (WTC)

Wavelet analysis was originally developed to highlight cycles in natural phenomena, but it has potential as an economic tool as well (Ramsey, 1999). The most important quality of Wavelet analysis is time-scale decomposition, which enables the analyst to study relationships between two time series, indicating cycles and particular levels of correlation in specified time periods, rather than for the whole period of the time series only (Durai and Bhaduri, 2009). This makes Wavelet analysis particularly useful for identifying relationships between two time series which are frequently changing their mutual relationship (Ramsey and Lampart, 1997).

Gallegati (2008) provided a comparison of the effectiveness of Wavelet and Fourier transforms for time series data. The main disadvantage of Fourier transform is that it cannot cope with non-stationary signals. This problem was partially solved by Gabor transform and short-time Fourier transform. The solutions are to divide the signal into many sections, called windows (they are consequently fixed – it means the resolutions in terms of time and frequency cannot be changed). Contrary, Wavelet analysis (wavelet = small wave) enables researchers to decompose time series into smaller windows, which are derived from larger time series. The complex time series is called the mother wavelet, which can be decomposed into scaled and translated sections (a scale is a detail of the time series and a translation is a window location). All of Wavelet analysis functions (CWT, XWT and WTC), which were employed in this study, are based on a transform of the mother wavelet of time series into its daughter wavelet. This relationship is outlined in the following equation:

$$\boldsymbol{\psi_{a,b}\,(t) = a^{-\frac{1}{2}}\,\psi\left(\frac{t-b}{a}\right)} \qquad \textbf{(\textit{3.1})}$$

where $\psi(t)$ symbolises a mother wavelet, $\psi_{a,b}\,(t)$ a daughter wavelet, a means the scale and b is the position. Several wavelets were compared (Haar, Meyer, Morlet and Mexican hat) and based on this comparisons and conclusions of other researches, the Morlet wavelet (equation below) was used for this research. The following equation indicates non-dimensional frequency ω and non-dimensional time η:

$$\boldsymbol{\psi_0\,(\eta) = \pi^{-1/4} e^{i\omega 0\eta} e^{\frac{-1}{2}\eta^2}} \qquad \textbf{(\textit{3.2})}$$

3.1 Continuous Wavelet Transform

Continuous wavelet transform (CWT) is a fundamental Wavelet analysis function that decomposes one time series into time and frequency space. CWT consequently helps to detect oscillations in time series. Grinsted *et al*. (2004) suggested that the Morlet wavelet gave the best balance between localisation in time and frequency which is the only solution to gain precise data of cycles (when they occurred and how often they repeated). Moore and Grinsted (2003) employed CWT to investigate ice conditions in the Baltic Sea. CWT is a function which in fact creates a figure of the wavelet power in units of normalised variance. It is the basic wavelet transform which aim is to identify cycles at one time series. This function can be expressed as:

[Wave,period,scale,coi,sig95]=cwt(d) **(*3.3*)**

This function includes following parameters:

- Wave – a wavelet transform of the time series
- Period – a vector of Fourier periods associated with a wave
- Scale – a vector wavelet scales associated with a wave
- Coi – a cone of influence
- Sig95 – 95% level of significance

The approach, how CWT was applied in this paper, was similar to Tonn *et al*. (2010) and Grinsted *et al*. (2004) where further information may be found.

3.2 Cross Wavelet Transform

Moore and Grinsted (2003) employed Cross wavelet transform (XWT), a function that allows a comparison of individual time periods and frequencies of two time series. Results of XWT analyse whether both time series are in the same phase or not (in phase – variables move the same direction together; anti phase – variables move the opposite direction), as well as which variable leads the other. XWT is a function that provides a figure of cross wavelet power in units of normalised variance. This function can be expressed as:

[W_{XY},period,scale,coi,sig95]=xwt(x,y) **(*3.4*)**

This function includes following parameters:

- W_{XY} – a cross wavelet transform of time series x against time series y
- Period – a vector of Fourier periods associated with W_{XY}
- Scale – a vector of wavelet scales associated with W_{XY}
- Coi – a cone of influence
- Sig95 – 95% level of significance

Torrence and Compo (1998) defined the cross wavelet power of two time series in an equation which was used for this research:

$$\boldsymbol{D}\left(\frac{|W_n^X(s)W_n^{Y*}(s)|}{\sigma_X\sigma_Y} < p\right) = \frac{Z_v(p)}{v}\sqrt{P_k^X P_k^Y} \qquad \textbf{(\textit{3.5})}$$

"where Z_v(p) is the confidence level associated with the probability p for a pdf defined by the square root of the product of two χ^2 distributions" (Grinsted *et al*., 2004: 563). The equation above also includes two time series x_n and y_n which are investigated. Their XWT is defined as $W^{XY}=W^XW^{Y*}$. The symbol * stands for complex conjugation. The approach, how XWT was applied in this paper, was similar to Tonn *et al*. (2010) and Grinsted *et al*. (2004) where further information may be found.

3.3 Wavelet Coherence

Wavelet coherence (WTC) was employed by Moore and Grinsted (2003) as well. Grinstead *et al*. (2004) emphasised an ability of WTC to identify periods where both time series co-vary. Tonn *et al*. (2010) continued that the WTC enabled a comparison of two time series to identify their local levels of correlation. It takes an advantage of XWT as well and identifies whether both variables are in the phase or not (the same as in XWT) and which variable leads. Thus, WTC is a function that provides a figure of cross wavelet power in units of correlation coefficient. This function can be expressed as:

[Rsq,period,scale,coi,sig95]=wtc(x,y) **(*3.6*)**

This function includes following parameters:

- Rsq - a cross wavelet correlation of time series x against time series y
- Period – a vector of Fourier periods associated with W_{XY}
- Scale – a vector of wavelet scales associated with W_{XY}
- Coi – a cone of influence
- Sig95 – 95% level of significance

WTC of two time series was defined by Torrence and Webster (1999) in the following equation:

$$R_n^2(s) = \frac{\left|S(s^{-1}W_n^{XY}(s))\right|^2}{S(s^{-1}\left|W_n^X(s)\right|^2) * S(s^{-1}\left|W_n^Y(s)\right|^2)} \quad (3.7)$$

where S indicates smoothing in both time and scale. As WTC measures local correlation (local in time and frequency) between two time series, its results range from 0 to 1. When the coefficient of correlation is equal to 1, it means that time series are locally correlated completely. Contrary, when the coefficient of correlation is equal to 0, there is no local correlation between time series.

For further information on the Wavelet analysis methodology the interested reader is directed to Tonn *et al*. (2010), Grinsted *et al*. (2004), Torrence and Webster (1999) and Torrence and Compo (1998). The Matlab source codes which were used for this paper are included in 6Appendix D6Appendix C. These source codes had been obtained from the Matlab Wavelet Coherence package (wtc-r16.zip; http://www.pol.ac.uk/home/research/waveletcoherence/download.html).

3.4 Data Collection

As the aim of this research was to investigate the price development of food commodity and agricultural raw material prices, 22 commodities, which are traded globally, were selected. These commodities were:

- Agricultural Raw Materials (Copra, Cotton, Jute, Sisal)
- Cereals (Maize, Rice, Wheat)
- Beverages (Cocoa Beans, Coffee Arabica, Coffee Robusta)
- Soybean Products (Soybean Meal, Soybean Oil, Soybeans)
- Vegetable Oils (Cottonseed Oil, Groundnut Oil, Linseed Oil, Palm Kernel Oil, Palm Oil, Sunflower Oil)
- Other (Bananas, Sugar, Tobacco)

Food commodity and agricultural raw material prices were compared with the prices of crude oil, gold and the US GDP growth. Crude oil is one of the most important inputs into agricultural activities and it is believed it has a major influence on food commodity and agricultural raw material prices. Thus, it was interesting to study whether commodity prices followed the same cycles and whether they were mutually correlated or not.

Gold is thought to be a hedge against uncertain economic conditions (Mayer, 2009). For instance, inflation tends to increase the demand and price of gold. This research answered the question if food commodity and agricultural raw material prices followed the same pattern in the short-term and if they had mutual relationship (i.e. whether unrelated commodities experienced co-movements or not).

The analysis of the relationship between the growth of the US GDP and commodity prices was studied to indicate if there really was a negative correlation between economic growth and food commodity/agricultural raw material prices. Thus, prices of investigated commodities were compared with the growth of the US GDP instead of the global one because:

- Economy of the United States was the biggest national economy worldwide within whole investigated period (1961 – 2010).
- Agricultural sector of the United States significantly contributed to agricultural commodity price determination.
- Availability of monthly data on world Gross Domestic Product are extremely speculative as data (e.g. from the period of existence of the Soviet Union) are only reliable estimates which are not reliable at all; even OECD group of countries were changing in the investigated period.

Data on the above variables were collected for the period between 1961 and 2010 from the following sources:

- Monthly US Consumer price index – US Department of Labour, Bureau of Labour Statistics
- Monthly data on all agricultural commodity prices – UNCTADstat (details about individual commodities are provided in 6Appendix C)
- Monthly data on the crude oil price – UNCTADstat
- Monthly data on the gold prices – Deutsche Bundesbank

- Monthly data on US GDP – Bureau of Economic Analysis, National Economic Accounts

All of these time series were checked for outliers, using descriptive statistics, particularly Box-plot analyses. The Box-plot shows graphically how individual data are spread across a range. Software Statistica 9.1 was used to perform Box-plot analysis (provided in 6Appendix E - 6E.1 for commodities and 6E.2 for variables).

All nominal prices were adjusted by US Consumer Price Index ALL Urban Consumers (CPI-U), 1982-84=100. This deflator had been chosen because it was considered as the deflator that effectively reflected changes in the prices paid by urban consumers (McCully *et al.*, 2007). The US deflator was used because food commodity and agricultural raw material prices are largely denominated in US$, minimising exchange rate confusions.

4 RESULTS

The method of Wavelet analysis provided 198 graphics of results. As the space of this paper is limited, only one graph of each analysis is included as an example. All detail results are included in 6Appendix A. Text version of main significant cycle results are summarised in 6Appendix B.

Figure 4.1 indicates the results of Continuous Wavelet Transform (CWT; it is changed – original figure did not include price development). The horizontal axis indicates the time of tobacco price series in years from 1961 to 2010 (investigated period). The vertical axis indicates a dynamic wavelet scale which measures a frequency of cycles (how often the same sequence of price development repeat). The diagram with spectrum scale (scalogram) indicates the volatility of tobacco price. The area inside the U-shaped curve picks out the cone of influence (statistically significant results; basically all data that can be seen). The areas which are highlighted by black circles are those where investigated commodity price experienced significant cycles.

Based on this explanation, Figure 4.1 can be interpreted as follows; tobacco price experienced significant cycles in 1994 (1/4 year frequency), between 1987 and 1994 (2 ½ year frequency) and between 1976 and 1982 (11 year frequency). Furthermore, an insignificant cycle from 1971 to 2002 (11 year frequency) is clearly visible as well.

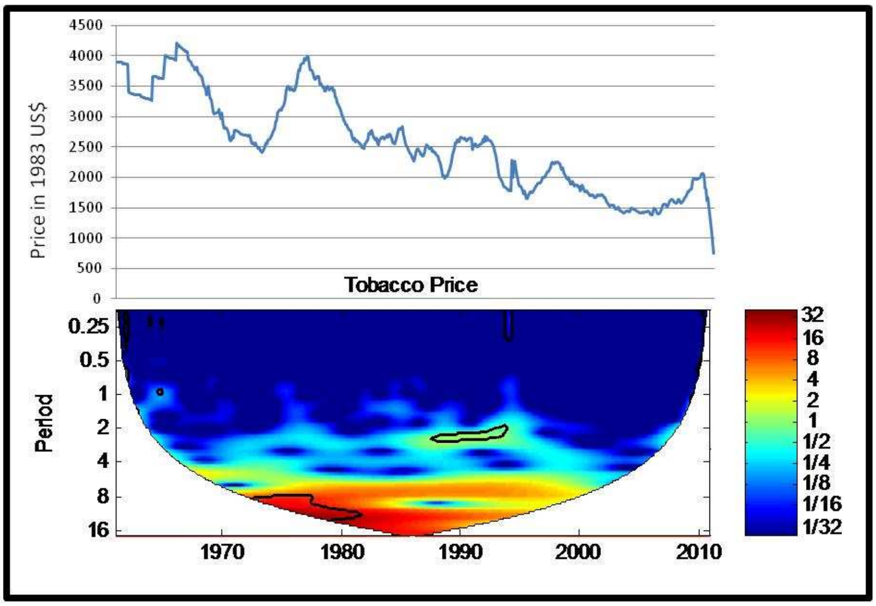

Figure 4.1 CWT Results – Scalogram/Diagram of Tobacco Price

Figure 4.2 shows the results from the Cross Wavelet Transform (XWT; it is changed – original figure did not include price development), where the horizontal and vertical axes indicate the same as at CWT. Contrary, the scalogram (right hand side legend) indicates the local covariance (local in time and frequency) between gold price and tobacco price. Furthermore, arrows, which are included in the following diagram (coscalogram; Figure 4.2), indicate whether prices were in phase (arrows point to right) or anti phase (point to left). Once they point up, it means that the first variable led another one and vice versa.

Figure 4.2 indicates one important significant cycle between gold and tobacco prices where the local covariance was very high. There was 8 year frequency cycle in 1970s and 1980s when price of both commodities were moving in the opposite direction (anti phase) and the price of tobacco was leading the price of gold. Another significant cycle (1978 – 1982) did not reach very high level of the local covariance. However, the commodities were significantly anti phase and tobacco price led gold price.

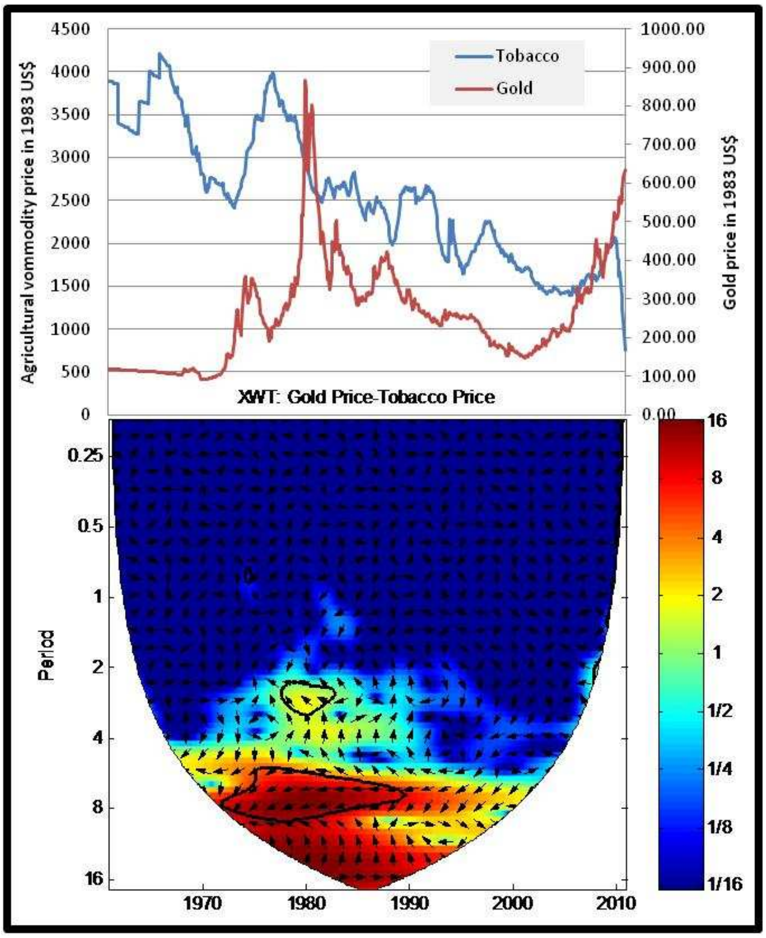

Figure 4.2 XWT Results – Coscalogram/Diagram of Gold and Tobacco Prices

The graph Figure 4.3 shows an example of a Wavelet Coherence (WTC; it is changed – original figure did not include price development), which shows the same results as XWT, except the scale indicates the level of local correlation instead of the local covariance. Figure 4.3 shows two main significant cycles where the levels of local correlation between crude oil and tobacco prices were very high. One cycle (which can be divided into two) occurred between 1978 and 1988 (3 year frequency) where crude oil price was leading the price of tobacco. Other significant cycle (4 year frequency) occurred between 1996 and 2000 where tobacco price was leading crude oil price. There are other significant cycles present, with high levels of local correlations but either they had extremely short duration (less than 1 year) or had a negligible frequency.

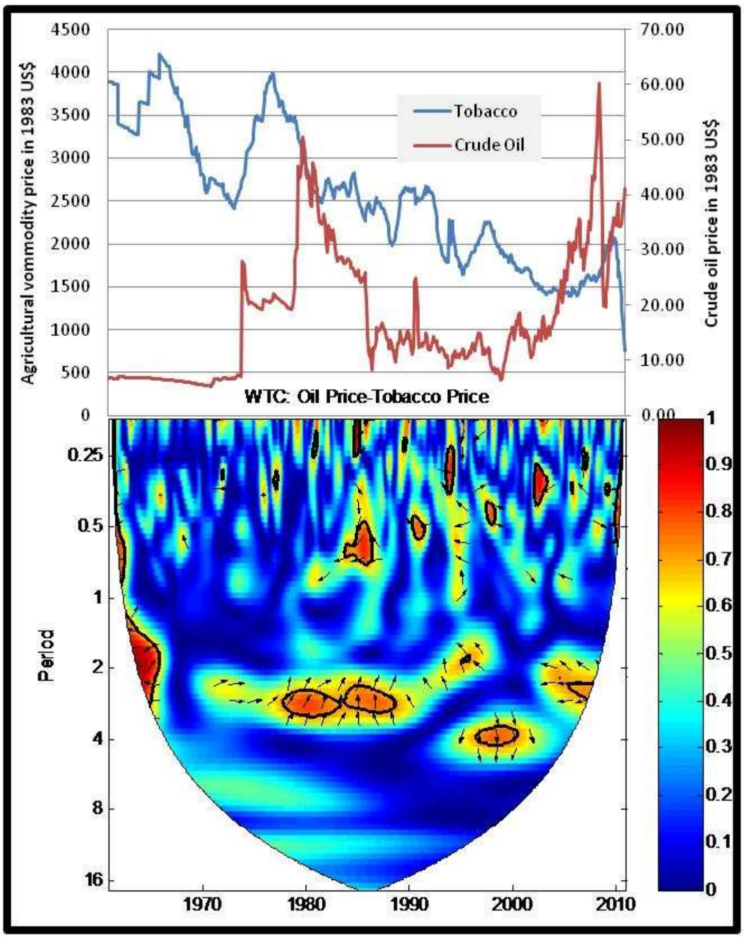

Figure 4.3 WTC Results – Crude oil Price and Tobacco Price

4.1 Continuous Wavelet Transform Results

CWT results revealed significant (statistically proven) and non-significant (highly probable, not statistically proven) cycles. Periods, when they occurred, and their frequency were revealed as well. The important highlights of results of 22 investigated commodities are summarised in Table 4.1.

Table 4.1 should be interpreted as follows; there are 81 independent significant cycles. Cycles of each commodity are represented in the appropriate row with a maximum of 7 significant cycles (for cottonseed oil). Each cycle holds information of its frequency, duration and time when it occurred. For instance, soybean meal experienced 2 significant cycles. The first one had a frequency of 2 years (each 2 years the commodity price completed the cycle: trough-peak-trough) and lasted 9 years (4.5 completed cycles of 2 year frequency occurred) from 1971 to 1979. The second one had a frequency of 4 years and lasted 7 years (1 ¾ completed cycles of 4 year frequency occurred) from 1971 to 1977.

Table 4.1 CWT Results – Main Significant Cycle Identification

(Fr = Frequency, Du = Duration, T = Time)

		Cycle 1			Cycle 2			Cycle 3			Cycle 4			Cycle 5			Cycle 6			Cycle 7		
	Commodity	Fr	Du	T	Fr	Du	T	Fr	Du	T	Fr	Du	T	Fr	Du	T	Fr	Du	T	Fr	Du	T
Agricultural Raw Materials	Copra	2	4	72-75	4	17	68-84	6	22	67-88												
	Cotton	2	4	85-88	4	6	69-84	6	3	70-72												
	Jute	3	5	83-87																		
	Sisal	1	1	63	2	11	72-82	6	17	68-84												
Cereals	Cocoa Beans	2	10	72-81	5	13	67-79	8	19	71-89												
	Coffee Arabica	2	6	75-80	3	24	74-97	4	11	71-81	8	18	73-90									
	Coffee Robusta	2	7	75-81	3	11	72-82	8	20	71-90												
Beverages	Maize	1.5	11	73-83	1.5	3	06-08	2	4	94-97	3	6	79-84	4	9	67-75	5	18	69-86			
	Rice	2	7	68-84	2	2	93-94	2	2	07-08	8	18	69-86									
	Wheat	0.25	1	08	0.5	1	08	1	4	79-82	2	9	70-78	2	4	06-09	8	16	68-83			
Soybean Products	Soybean Meal	2	9	71-79	4	7	71-77															
	Soybean Oil	1	2	83-84	2	7	73-79	2	2	07-08	2	3	63-65	5	21	67-87						
	Soybeans	1	1	83	2	10	71-80	4	7	71-77												
Vegetable Oils	Cottonseed Oil	0.5	3	83-85	0.6	3	83-85	0.8	3	83-85	1	2	02-03	2	6	73-78	3	11	68-78	6	13	71-83
	Groundnut oil	2	4	72-85	6	24	68-91															
	Linseed Oil	1	1	05	2	9	71-79	2	5	05-09	3	5	04-08	4	24	67-90						
	Palm Kernel Oil	1	3	67-69	1	2	83-94	2	10	71-80	3	19	67-85	6	20	68-87						
	Palm Oil	2	10	72-81	5	22	67-88															
	Sunflower Oil	1	25	84-08	1	1	84	2	8	73-80	3	3	06-08	5	21	66-86						
Other	Bananas	1	4	77-80	1	5	82-86	1	7	88-94	1	2	05-06									
	Sugar	2	14	71-84	6	7	68-74															
	Tobacco	0.25	1	94	2.5	8	87-94	11	11	72-82												

4.1.1 Continuous Wavelet Transform Results Interpretation

Figures Figure 4.4, Figure 4.5 and Figure 4.6 provide a graphical interpretation of the results from Table 4.1. Figure 4.4 indicates years when the price of particular commodity was in a significant cycle with the frequency lower than 4 years, Figure 4.5 indicates significant cycles with frequencies from 4 to 6 years and Figure 4.6 indicates 7 and more year frequency significant cycles. These figures indicate the periods when food commodity and agricultural raw material prices experienced significant cyclical behaviour.

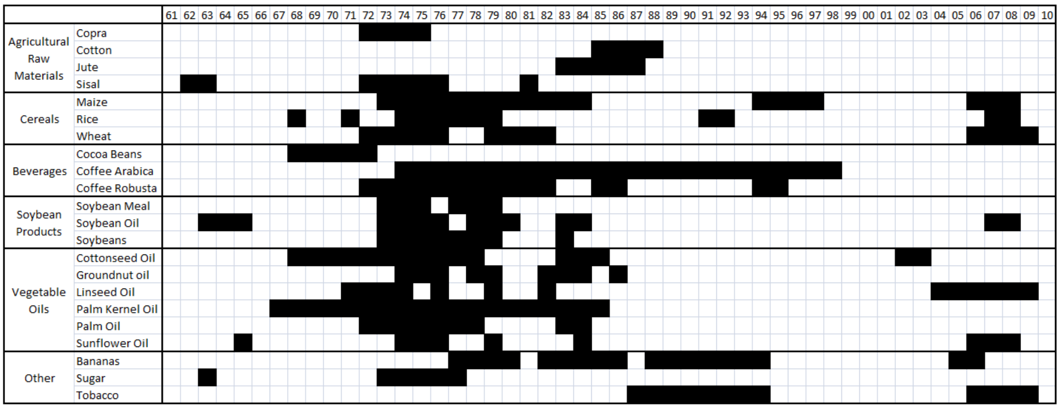

Figure 4.4 CWT – Main Significant Cycles (frequencies lower than 4 years)

(horizontal axis = years; vertical axis = agricultural commodities)

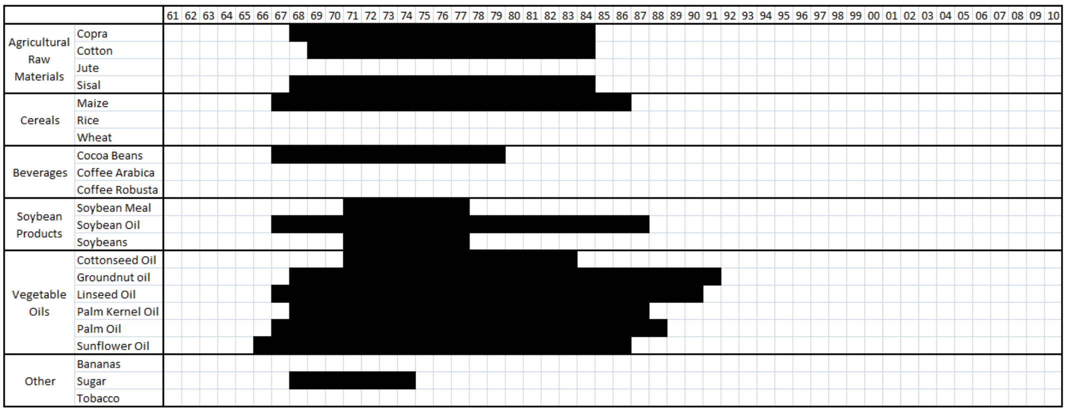

Figure 4.5 CWT – Main Significant Cycles (frequencies from 4 to 6 years)

(horizontal axis = years; vertical axis = agricultural commodities)

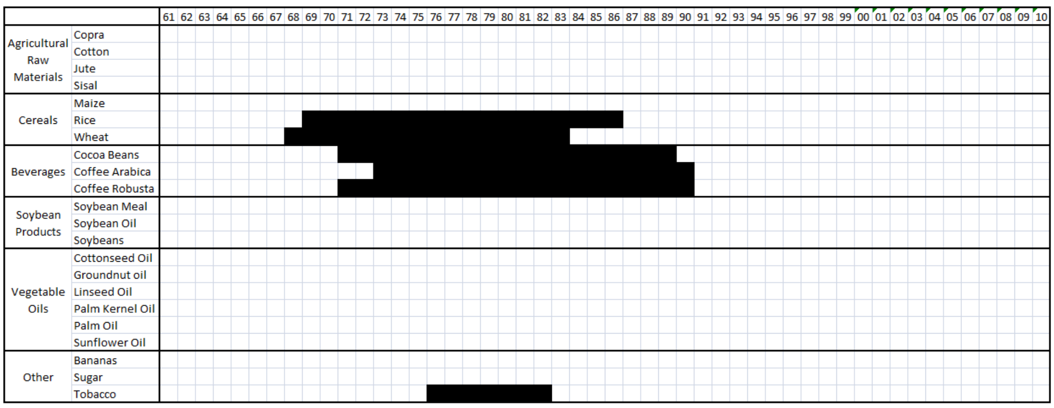

Figure 4.6 CWT – Main Significant Cycles (frequencies 7 years and more)

(horizontal axis = years; vertical axis = agricultural commodities)

Table 4.2 shows significant cycles of prices of individual investigated commodities. It shows the number of significant cycles these prices of individual commodities experienced. Average significant cycle frequencies and durations of individual commodity prices are included as well. Table 4.2 shows that cottonseed oil experienced 7 significant cycles (the most), the highest average frequency of significant cycles had cocoa beans and tobacco (5 years), and the lowest had bananas with only 1 year frequency. The longest significant cycles (in average) experienced palm oil (16 years long) and the shortest cotton (4.3 years long).

Table 4.2 Main Significant Cycles

Values of their Frequencies and Durations (in years)

	Commodity	Number of Cycles	Average Frequency	Average Duration
Agricultural Raw Materials	Copra	3	4.0	14.3
	Cotton	3	4.0	4.3
	Jute	1	3.0	5.0
	Sisal	3	3.0	9.7
Cereals	Maize	6	3.0	8.7
	Rice	4	3.5	7.3
	Wheat	6	2.5	5.8
Beverages	Cocoa Beans	3	5.0	14.0
	Coffee Arabica	4	4.3	14.8
	Coffee Robusta	3	4.3	12.7
Soybean Products	Soybean Meal	2	3.0	8.0
	Soybean Oil	5	2.4	7.0
	Soybeans	3	2.3	6.0
Vegetable Oils	Cottonseed Oil	7	2.1	5.9
	Groundnut oil	2	4.0	14.0
	Linseed Oil	5	2.4	8.8
	Palm Kernel Oil	5	2.6	10.8
	Palm Oil	2	3.5	16.0
	Sunflower Oil	5	2.4	11.6
Other	Bananas	4	1.0	4.5
	Sugar	2	4.0	10.5
	Tobacco	3	5.0	6.7

Table 4.3, and its graphical representation Figure 4.7, reveal the most common frequencies when food commodity and agricultural raw material prices experienced a significant cyclical behaviour (based on CWT results). Generally,

the majority of commodities experienced cycles with a frequency lower than 7 years, 5 investigated commodity prices had a significant cycle with a frequency of 8 years. However, tobacco price experienced the cycle with the highest frequency of 11 years.

Table 4.3 Main Significant Cycle Frequencies and Number of Occurrences

Frequency (in years)	1	2	3	4	5	6	7	8	9	10	11
Occurrences	20	27	9	7	5	7	0	5	0	0	1

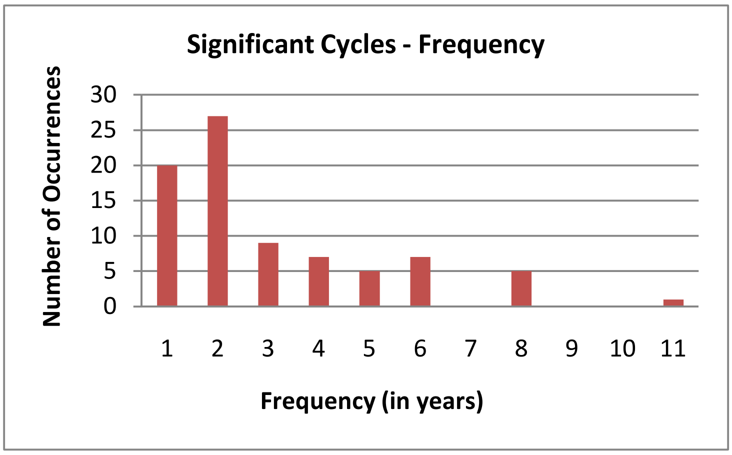

Figure 4.7 Main Significant Cycle Frequencies and Number of Occurrences

Significant cycles of investigated commodity prices had a very wide range of durations. Almost half of significant cycles were shorter than 6 years. Contrary, coffee arabica, copra, groundnut oil, linseed oil, palm oil, soybean oil and sunflower oil (2 times) experienced cycles of various frequencies which duration ranged between 21 and 25 years. Commodity prices that experienced longer durations of cyclical behaviour have a higher potential to be at least partially predictable. Duration of significant cycles is summarised in Table 4.4 and Figure 4.8 (graphical representation).

Table 4.4 Main Significant Cycle Durations and Number of Occurrences

Duration (in years)	1 – 5	6 – 10	11 – 15	16 – 20	21 – 25
Occurrences	36	20	8	9	8

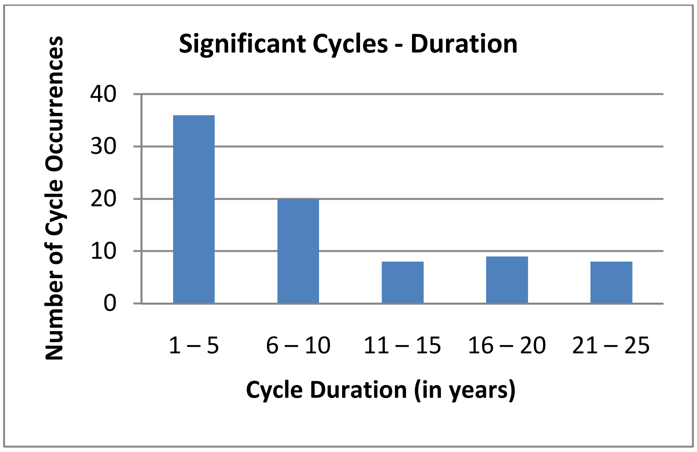

Figure 4.8 Main Significant Cycle Durations and Number of Occurrences

4.2 Cross Wavelet Transform Results

The results of XWT provided 66 graphs that indicate local covariance (local in time and frequency) between one of 22 investigated commodities and 1) US GDP growth (G), 2) crude oil price (P) and 3) gold price (GP). Furthermore, the results of XWT indicated time and frequency of local covariance, whether they were in phase or anti phase and identification which variable led. The significant highlights of 22 investigated commodities are summarised in Table 4.5.

Table 4.5 XWT Results – Main Significant Local Covariance

(Fr = Frequency in years, HF = Various High Frequencies; CR = Correlation Relationship; L = Led by, C = Agricultural Commodity, G = US GDP Growth, P = Crude oil Price, GP = Gold Price)

		US GDP Growth				Crude Petroleum Price				Gold Price			
	Commodity	Time	Fr	CR	L	Time	Fr	CR	L	Time	Fr	CR	L
Agricultural Raw Materials	Copra	70s-80s	HF	anti phase	C	70s-80s	HF	in phase	P	70s-mid 80s	HF	in phase	GP
	Cotton	70s	HF	anti phase	C	70s	3	in phase	P	70s	7	in phase	
	Jute	1982-1986	3	anti phase		1978-1986	5	in phase	P	1978-1984	5		GP
	Sisal	70s-mid 80s	HF	anti phase	C	70s-mid 80s	HF	in phase		70s-80s	HF	in phase	
Cereals	Maize	mid 60s-mid 80s	HF	anti phase		70s-mid 80s	HF	in phase		70s-mid 80s	HF	in phase	
	Rice	70s-mid 80s	HF	anti phase	C	70s	HF	in phase		70s-80s	HF	in phase	
	Wheat	70s-mid 80s	HF	anti phase	C	70s	5	in phase	P	70s-80s	HF	in phase	
Beverages	Cocoa Beans	70s-80s	HF	in phase	C	70s-mid 80s	HF	anti phase	P	70s-80s	HF	anti phase	GP
	Coffee Arabica	70s-80s	HF	in phase	C	70s-mid 80s	HF	anti phase		70s-80s	HF	anti phase	GP
	Coffee Robusta	70s-80s	HF	in phase	C	70s-mid 80s	HF	anti phase		70s-80s	HF	anti phase	GP
Soybean Products	Soybean Meal	70s	HF		C	70s	5	anti phase	P	70s	HF	in phase	GP
	Soybean Oil	70s-80s	HF	anti phase	C	70s-80s	5	in phase	P	70s-mid 80s	HF	in phase	GP
	Soybeans	70s	HF		C	70s	5	anti phase	P	70s	HF	in phase	GP
Vegetable Oils	Cottonseed Oil	70s	HF	anti phase	C	70s-80s	HF	in phase	P	70s-80s	HF	in phase	
	Groundnut oil	70s-80s	HF	anti phase	C	70s-80s	HF	in phase	P	70s-80s	HF	in phase	GP
	Linseed Oil	70s-80s	HF	anti phase	C	70s-mid 80s	HF	in phase		70s-80s	HF	in phase	
	Palm Kernel Oil	70s-80s	HF	anti phase	C	70s-mid 80s	5	in phase	P	70s-80s	HF	in phase	GP
	Palm Oil	70s-80s	HF	anti phase	C	70s-mid 80s	5	in phase	P	70s-mid 80s	HF	in phase	GP
	Sunflower Oil	70s-mid 80s	HF	anti phase	C	70s-mid 80s	5	in phase	P	70s-mid 80s	5	in phase	GP
Other	Bananas	end 70s-mid 80s	1	in phase	G	70s-80s	1			70s-mid 90s	8	anti phase	C
	Sugar	70s-mid 80s	HF	anti phase		70s-mid 80s	HF	in phase		70s-80s	HF	in phase	
	Tobacco	1975-1985	7	in phase	G	[redacted]				70s-80s	8	anti phase	C

4.3 Wavelet Coherence Results

Results of WTC adds to those of the XWT and shows local correlation (local in time and frequency) between each of 22 investigated commodities and 1) US GDP growth (G), 2) crude oil price (P) and 3) gold price (GP). The results of WTC showed the time, frequency, correlation relationship (whether they were in phase or anti phase) and identified the leading variable. Periods with high levels of local correlation and information about the experienced significant cycles are summarised in tables Table 4.6 for US GDP growth, Table 4.7 for crude oil price and Table 4.8 for gold price.

Table 4.6 WTC Results – Main Significant Cycles with US GDP Growth

(Fr = Frequency in years; CR = Correlation Relationship; L = Led by, C = Agricultural Commodity, G = US GDP Growth, P = Crude oil Price, GP = Gold Price)

		Cycle 1				Cycle 2				Cycle 3			
	Commodity	Time	Fr	CR	L	Time	Fr	CR	L	Time	Fr	CR	L
Agricultural Raw Materials	Copra	1970-1975	6	anti phase	C	1987-1988	1/2	anti phase	C	1991-1996	2	in phase	
	Cotton												
	Jute	80s, 90s	9	in phase		90s	2	in phase	G				
	Sisal	70s-mid 80s	6	anti phase	C								
Cereals	Maize	1967-1975	6	anti phase		1981-1985	2	in phase	C	2004-2007	2	anti phase	
	Rice	70s, 80s	6	anti phase		1990-1997	2	in phase	G				
	Wheat	70s	6	anti phase	C								
Beverages	Cocoa Beans												
	Coffee Arabica	70s-90s	12	in phase	C								
	Coffee Robusta	70s-90s	12	in phase	C								
Soybean Products	Soybean Meal	70s	6		C	1987-1988	1/2		C	2000-2009	3		C
	Soybean Oil	1970-1975	4	anti phase		1977-1981	1	in phase	G	2004-2009	3		C
	Soybeans	70s	6		C	1985-1995	4	in phase		2000-2009	3		
Vegetable Oils	Cottonseed Oil	1968-1973	6	anti phase	C	1988-1989	1/2	anti phase	C				
	Groundnut oil	1968-1991	5	anti phase	C	1995-1999	1		C				
	Linseed Oil	70s	6	anti phase		1986-1993	4		C				
	Palm Kernel Oil	1981-1985	2		C	1988	1/2		C	1991-1996	2	in phase	C
	Palm Oil	1969-1975	4	anti phase		1991-1994	2	anti phase	C				
	Sunflower Oil	1970-1975	4	anti phase									
Other	Bananas	many 1/2 year cycles											
	Sugar	70s-80s	6	anti phase									
	Tobacco	1991-1997	2	in phase									

Table 4.7 WTC Results – Significant Cycles with Crude oil Price

(Fr = Frequency in years; CR = Correlation Relationship; L = Led by, C = Agricultural Commodity, G = US GDP Growth, P = Crude oil Price, GP = Gold Price)

		Cycle 1				Cycle 2				Cycle 3			
	Commodity	Time	Fr	CR	L	Time	Fr	CR	L	Time	Fr	CR	L
Agricultural Raw Materials	Copra	70s-80s	6		P	1970-1975		in phase					
	Cotton	1968-1975	1-3		P	1985-1996	2	in phase	C				
	Jute	1974-1997	9	anti phase	C	1989-1991	1	anti phase	C				
	Sisal	70s-80s	6	in phase		2004-2009	2	in phase	C				
Cereals	Maize	1969-1988	6	in phase	P	1971-1974	1.5	anti phase	C	2005-2007	2	in phase	C
	Rice	1969-1973	2	in phase	P	1974-1983	7	in phase		2004-2007	2		C
	Wheat	70s-mid 80s	8	in phase		1994-1998	1	anti phase	C				
Beverages	Cocoa Beans	1971-1983	5	anti phase	P	1989-1993	1.5	in phase	P	1997-2002	4	anti phase	
	Coffee Arabica	70s-80s	8	anti phase		1976-1980	3	in phase		1997-1999	1	anti phase	
	Coffee Robusta	70s-80s	7	anti phase		1975-1981	1	in phase					
Soybean Products	Soybean Meal	1968 and 1975	1.5	anti phase	C	1997-2001	1		C	2007-2008	0.75	in phase	P
	Soybean Oil	70s-80s	6	in phase	P	2004-2009	2	in phase					
	Soybeans	1969-1975	1.5	anti phase	C	1996-2000	1	anti phase	C				
Vegetable Oils	Cottonseed Oil	70s-80s	5	in phase	P	2003-2009	3	in phase					
	Groundnut oil	1970-1974		in phase		70s-80s	6	in phase	P	2006-2009	3	in phase	C
	Linseed Oil	70s-80s	6	in phase	P	1968-1975	2	in phase	P				
	Palm Kernel Oil	70s-80s	6	in phase	P	1970-1975	1	in phase		2004-2009		in phase	
	Palm Oil	70s-80s	6	in phase	P	2004-2009		in phase					
	Sunflower Oil	70s-80s	6	in phase	P	2004-2009	2	in phase					
Other	Bananas												
	Sugar	70s-80s	5	in phase		1998-2001	3		C				
	Tobacco	1978-1988	3		P	1996-2000	4		C				

Table 4.8 WTC Results – Significant Cycles with Gold Price

(Fr = Frequency in years; CR = Correlation Relationship; L = Led by, C = Agricultural Commodity, G = US GDP Growth, P = Crude oil Price, GP = Gold Price)

		Cycle 1				Cycle 2				Cycle 3			
	Commodity	Time	Fr	CR	L	Time	Fr	CR	L	Time	Fr	CR	L
Agricultural Raw Materials	Copra	1980-1986	2	anti phase		6x 1 year cycles							
	Cotton	1983-1988	3	in phase	C	many 1 year cycles							
	Jute	1980-1993	9	anti phase		1994-1998	3	in phase	GP				
	Sisal	1969-1982	7	in phase		2002-2009	4	anti phase	C	2005-2009	2	in phase	C
Cereals	Maize	1969-1973	6	in phase		2004-2007	3		C				
	Rice	1969-1996	7	in phase	C	1981-1991	3		C				
	Wheat	1968-1982	6	in phase	GP	2001-2002	0.75	anti phase					
Beverages	Cocoa Beans	1972-1975	0.75	in phase	C	1975-1992	6	anti phase	GP	2006-2007	1	in phase	C
	Coffee Arabica	70s-80s	8	anti phase	GP	1991-1997	2	anti phase	C				
	Coffee Robusta	70s-80s	8	anti phase	GP	1991-1998	2	anti phase	C				
Soybean Products	Soybean Meal	1972-1999	8	in phase									
	Soybean Oil	1989-1991	3	in phase	C								
	Soybeans												
Vegetable Oils	Cottonseed Oil	1979-1984	2	anti phase	C								
	Groundnut oil	80s	3	in phase	C								
	Linseed Oil	70s-mid 80s	6	in phase		1990	1	anti phase	GP				
	Palm Kernel Oil	1972-1975	0.75	in phase		1980-1986	2	anti phase		1999-2004	1	in phase	
	Palm Oil												
	Sunflower Oil												
Other	Bananas	1980-1982	1	anti phase	C	1981-1984		in phase					
	Sugar	70s-90s	7	in phase		1980-1986	3	in phase	C				
	Tobacco	1976-1991	6	anti phase		2000		anti phase		2005-2009	3	anti phase	

5 DISCUSSION

5.1 Cycles in Investigated Commodity Prices

As the empirical results of this paper indicated, most of low frequency significant cycles (1 – 3 years) of investigated food commodity and agricultural raw material prices occurred precisely in 1974 when 17 out of 22 investigated commodities were experiencing a low frequency significant cycle. Only bananas, cacao beans, cotton, jute and tobacco were not in the low frequency significant cycle in 1974. This significant cyclical behaviour of investigated commodity prices continued till the end of 1970s and was almost completely eliminated till the mid 1980s.

The exceptions were prices of bananas (Figure 5.1), coffee arabica, coffee robusta, rice and tobacco. Prices of these commodities experienced low frequency significant cycles during 1990s as well. Only 9 commodities (bananas – Figure 5.1, cottonseed oil, linseed oil, maize, rice, soybean oil, sunflower oil, tobacco and wheat) experienced low frequency significant cycles after 2000, but these low frequency cycles did not have a long duration (less than 3 years except linseed oil, tobacco and wheat). Mid frequency (4-6 years) and high frequency (7 and more years) significant cycles occurred only in the 1970s and 1980s and they were experienced by all investigated commodities except bananas (Figure 5.1) and jute.

Bananas price development and its changed CWT diagram (price development was added) are shown in Figure 5.1. As bananas fluctuated and created many cycles with frequency of 1 year, the significant cycles are highlighted in Figure 5.1. Evidence of significant cycles almost in all decades is presented there.

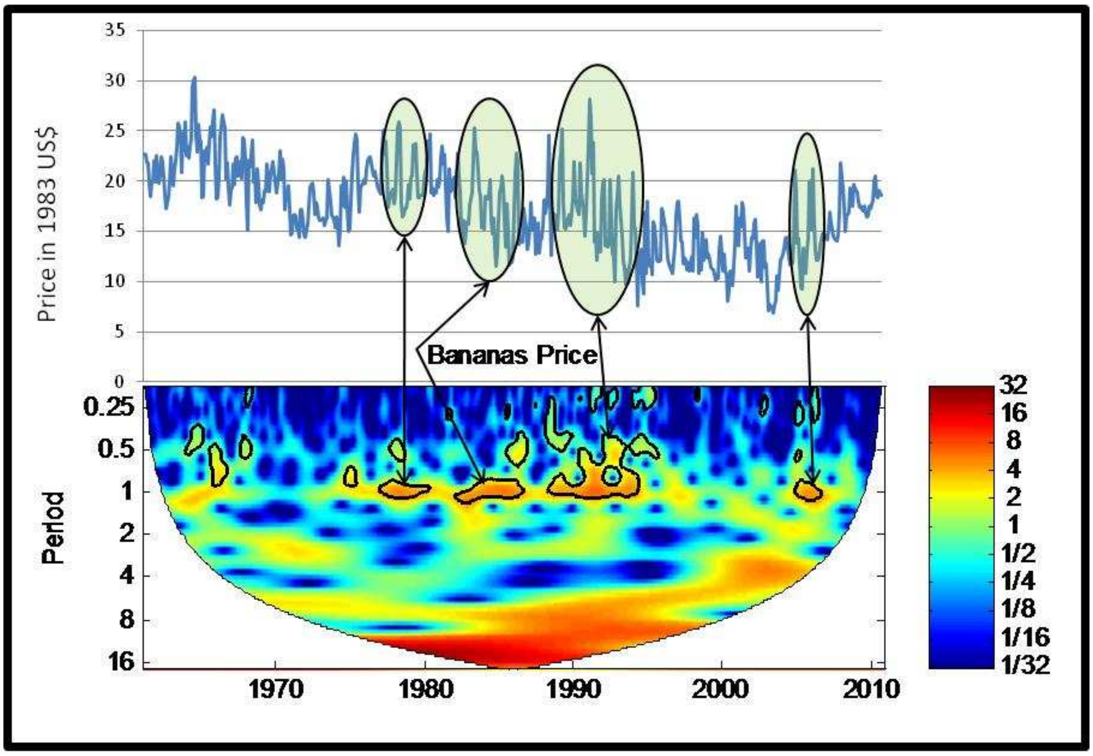

Figure 5.1 Bananas Price and CWT Diagram

Upper graph – real price of bananas in 1983 US$, horizontal axis corresponds with lower graph – years; Lower graph – CWT Diagram of bananas price; Diagrams for other commodity prices are included in Figure_Apx 1.

As the 1970s was a period when food commodity and agricultural raw material prices experienced the most significant cyclical behaviour, they were the major period of the concern for this study. Oil crises (which peaked mainly in late 1972 with crude oil price at almost 40 US$/barrel in 1983 US$) were very influential in these cycles (Nazlioglu, 2011). Additionally to these results, according to Wang *et al*. (2010), the main co-variables of food commodities and agricultural raw materials except the price of crude oil were the auction times for cereals, a market transaction volume and weather and climate conditions. Nevertheless, the research of Naccache (2011) corresponded results of this paper; the importance of crude oil price as a determinant of macroeconomic cycles had been weakening. In fact, only one significant cycle was led by the crude oil price after 2000 (case of soybean meal in 2007 and 2008).

The number of different durations of significant cycles provided a hint of which business cycle dominated food commodity and agricultural raw material prices. The results of this paper indicate that investigated commodity prices followed Kitchin cycle (21 significant cycles). According to Kitchin (1923), cycles with a frequency between 3 and 5 years were being caused by imperfect information (lags in information movement). Although the level of output of food commodities and agricultural raw materials could be increased or decreased (based on the demand), producers reacted to demand with delays which caused price cycles. The supply-demand information lags occurred mainly between decisions on what commodity should be produced and the harvest itself. Consequently, other gaps occurred between harvests and sales of individual commodities.

Several commodities experienced cycles with higher frequencies as well. Frequencies between 6 and 11 years, which the literature defines as Juglar cycles (Juglar, 1862), are attributed to investments into machinery, land and other fixed capital. As these investments were usually associated with step changes in production, their implementation was complicated and time demanding. These lags between production/investment decisions and harvests/sales contribute to prices cycles. There were totally 13 significant cycles of the investigated commodity prices with frequencies which inclined to Juglar cycle.

Food commodity and agricultural raw material prices experienced 47 significant cycles which were shorter than 3 years. Their short-term impact was very important. They were usually caused by 1) weather conditions which affected yields of individual commodities in particular season and 2) oscillations at a financial market as a commodity market and a financial market were negatively correlated (Mayer, 2009). Although commodity stocks have power to minimise these impacts, usually they do not do so as they are being use to further speculations (market speculators keep them to increase the price even more) or are restricted to decrease below minimal levels (governments intervene to ban all exports of particular commodities).

Based on the results of this paper and de Groot and Franses (2011), which divided all socio-economic cycles into 4 cluster (based on their duration), it is interesting that food commodity and agricultural raw material prices are included in the shortest cluster with mean cycle 8.423 years. Thus, investigated commodity cycles are rather short-term phenomena than other economic and social phenomena.

The research of this paper indicated that commodity prices did not simply follow linear trend. It was confirmed that commodity prices had fluctuated and often they had fluctuated in cycles. Related commodities usually experienced cyclical behaviour in the same period. Furthermore, there were periods when even unrelated commodities fluctuated in cycles together. Based on these findings, it is crucial that governments adjust their policies to the dynamic non-linear behaviour of commodity prices. Although the majority of discovered significant cycles had a frequency lower than 3 years, 34 significant cycles had a higher frequency which must force governments to plan governmental strategies for food security in advance with consideration of future needs.

5.2 Co-Movements of Commodity Prices and Variables

The research in this paper found that in general food commodity and agricultural raw material prices had not been led by the GDP growth. The XWT revealed only two cases of bananas (significant cycle in the end of 1970s and the beginning of 1980s) and tobacco (7 year cycle between 1975 and 1985) being led by the US GDP growth. Although it could be just a coincidence, it could happen as the rise in GDP caused higher demand for these commodities. However, especially the price of bananas is suspicious to be led by US GDP growth rather accidentally as the price of bananas regularly experienced significant cycles in the frequency which only twice occurred in the relationship with US GDP growth.

The price of crude oil and gold was found to lead significant cycles of 13 commodities out of 22 (crude oil with cocoa beans, copra, cotton, cottonseed oil, groundnut oil, jute, palm kernel oil, palm oil, soybean meal, soybean oil, soybeans, sunflower oil and wheat) and 12 times out of 22 (gold with cocoa beans, coffee arabica, coffee robusta, copra, groundnut oil, jute, palm kernel oil, palm oil, soybean meal, soybean oil, soybeans and sunflower oil). Only cotton, cottonseed oil and wheat were influenced only by crude oil price and not also by gold price.

Furthermore, WTC indicated that the crude oil price was leading price of investigated commodities and was locally correlated in 16 cases; this appeared with cocoa beans (2 significant cycles), copra (this relationship is highlighted in Figure 5.2 – crude oil price led copra price in the 1970s and 1980s), cotton, cottonseed oil, groundnut oil, linseed oil (2 significant cycles), maize, palm kernel oil, palm oil, rice, soybean meal, soybean oil, sunflower oil and tobacco. These correlated significant cycles were occurring predominantly in the 1970s through the oil crises. Thus, the price of crude oil had a significant effect on production of food commodities and agricultural raw materials as it was (and still is) one of the most important inputs to agricultural production (fertilisers, fuel, transport; Mikkola and Ahokas, 2010). Naturally, the fluctuation in the price of crude oil affected the price of all commodities, some more than others as it depended on the form of production (fuel requirements).

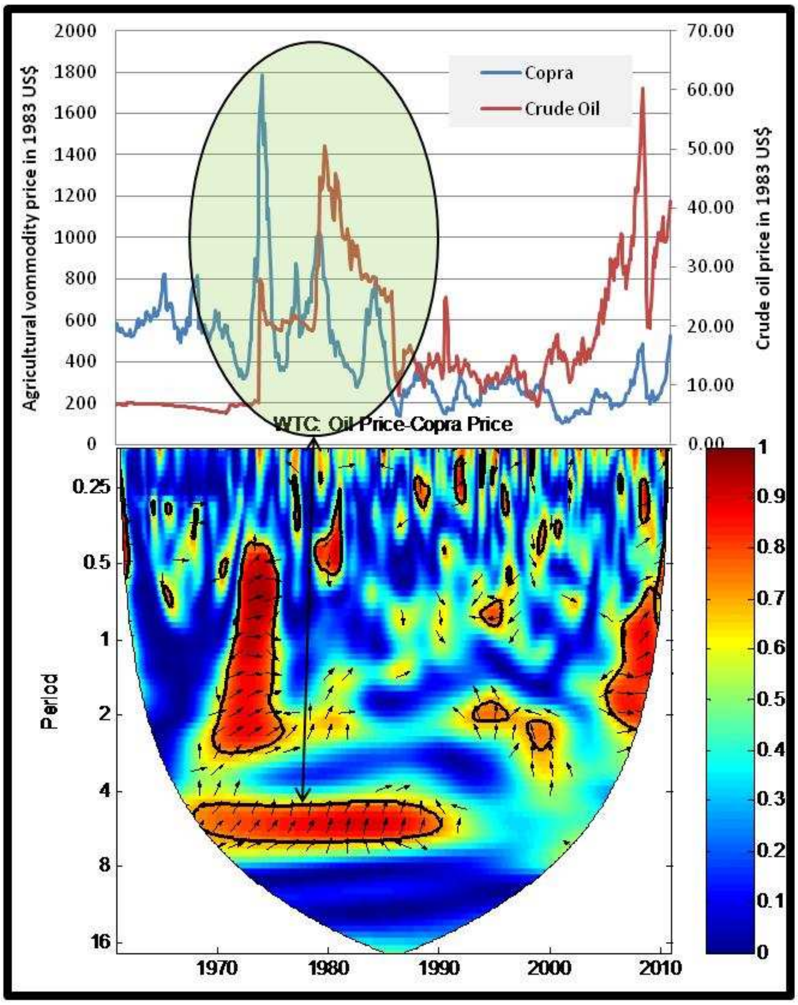

Figure 5.2 Crude Oil and Copra Prices and WTC Coscalogram/Diagram

Upper graph – real prices of crude oil and copra; left vertical axis – price of copra, right vertical axis – price of crude oil; prices in 1983 US$

However, the WTC results indicated that XWT gave gold price an inappropriate importance. WTC indicated only 6 significant cycles with high level of correlation between gold price and prices of cocoa beans, coffee arabica, coffee robusta, jute, linseed oil and wheat (the price of crude oil led 16 correlated significant cycles). Except for linseed oil, these commodity prices experienced significant cycles of at least 14 years duration during which they were correlated with gold price. Anyway, it evidences that these 6 commodities followed the high frequency cycle of gold price. As the real price of gold peaked in the end of 1970s and started to rise after 2000 again, these commodity prices moved in the same way. It can be assigned to increasing scarcity indicators which drove prices of these investigated commodities. Naturally, the price of gold reflected its very high level of scarcity as well.

As discussed by Deaton (1999), cycles in food commodity and agricultural raw material prices particularly caused by crude oil prices may have harmful effects on many developing countries, which depend on the export of these commodities. Unpredictable price fluctuations, in the crude oil prices, may significantly affect national accounts of these developing countries and negatively contributes to nutrition, education, health service and other important issues which extremely pain local populations. Based on the research of this paper and Wang *et al*. (2010), the price crude oil is one of the decisive factors which influenced agricultural commodity prices volatility.

5.3 Study Weaknesses and Further Research

This study concentrated generally on the cycles of food commodity and agricultural raw materials. Although the main cycles were identified and interpreted by the Wavelet analysis method, which is the most appropriate according to author's knowledge, there may arise misunderstandings between this study and others like cycle identification (trough-peak-trough, peak-trough-peak, trough-peak, and peak-trough). The disadvantage of this study (and Wavelet analysis) is that the result presentation is shown in diagrams. Although the main significant cycles were described in the text and table forms, less important smaller and insignificant cycles were not analysed. It was impossible to cover so many results in this paper.

Thus, further research should aim to analyse commodities individually with precise identification and interpretation of all cycles (low and high frequency, short and long duration, significant and insignificant) to obtain detailed results of individual commodities. Further research should include other explanatory variables (weather index, speculation index, volatility index, inflation rate, exchange rate, stock levels) to interpret the volatility and cyclical behaviour of food commodity and agricultural raw material prices in detail.

6 CONCLUSION

Wavelet analysis was employed in this study to investigate the cyclical behaviour of food commodity and agricultural raw material prices. The results suggested that the prices of the majority of investigated commodities experienced mostly low frequency significant cycles in the mid 1970s, some of the cyclical behaviour of prices continued in the 1980s, 9 commodities underwent short-term low frequency significant cycles after 2000, predominantly between 2006 and 2008 before the advent of the credit crisis. The wavelet analysis did not detect any significant cycles in the 1990s.

The results of this study suggested that the cyclical behaviour can be explained predominantly by the prices of crude oil and gold. The prices of these commodities were experiencing cyclical behaviour in the same periods as prices of investigated commodities. The XWT function indicated that the price of crude oil had led commodity prices 13 times, and gold led twelve times. The influence of economic output (indicated by US GDP growth) had a negligible effect on food commodity and agricultural raw material prices. Furthermore, weather conditions, market volume, speculation and level of stocks were important factors in determination fluctuation and price cycles as well, but these were not investigated.

It was confirmed that the high local correlation levels had occurred between investigated commodity prices and crude oil price. This showed co-movements of these variables and their interdependency. Contrary to XWT results, WTC results did not confirm major significant correlation between investigated commodity prices and gold price. The US GDP growth had been correlated with investigated commodity prices only in 3 significant cycles which rejected a theory of any significant co-movements between these variables.

The significant co-movement of investigated commodity prices and the crude oil price can be explained by a significant proportion of fertiliser and fuel costs on production costs of many food commodities and agricultural raw materials. Although it was not the subject of this paper, this conclusion was confirmed based on a review of the literature. Co-movement is being strengthened by present Biofuels production as well. Furthermore, world population is increasing the demand for crude oil and investigated commodities as well. It elicits a simultaneous independent co-movement.

Food commodity and agricultural raw material prices experienced many significant and insignificant cycles. Based on the results of last 50 years, it can be hypothesised that the prices of investigated commodities will follow the same pattern. Thus, governments and other policy makers should tailor their strategies for food security to volatile cycles rather than continuous uni-directional movements in commodity prices. These governments and policy makers should emphasise mainly longer periods corresponding to Juglar cycles (6 – 11 years) which requires planning ahead. Successful policies should have an ability to minimise these cycles in future.

As this research aimed to investigate cycles of food commodity and agricultural raw material prices generally with global perspective, further research should be undertaken to deeply analyse individual commodity prices. Such research should include other variables like a weather condition index, an index which reflects a speculation with agricultural commodities, level of stocks of particular commodity, etc. Similar variables have a collective power to explain fluctuation and cyclical behaviour of food commodity and agricultural raw material prices in detail and provide plenty of ground to explain impacts and reasons of individual price fluctuations.

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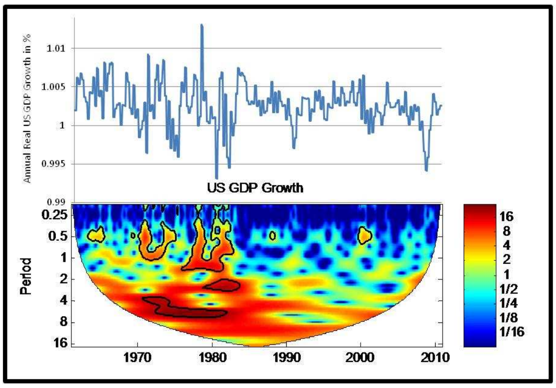
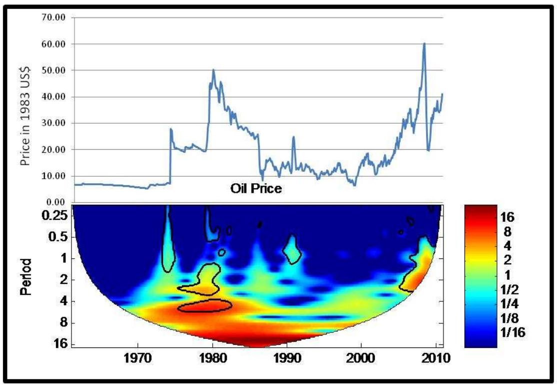
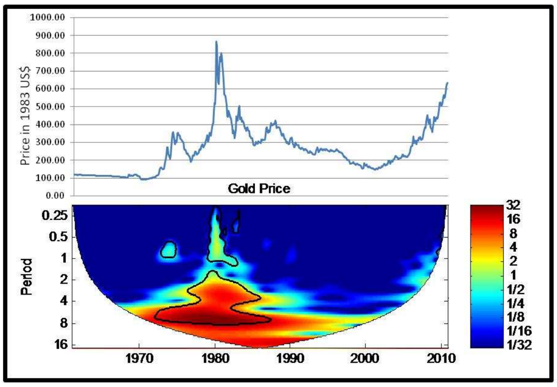
APPENDICES

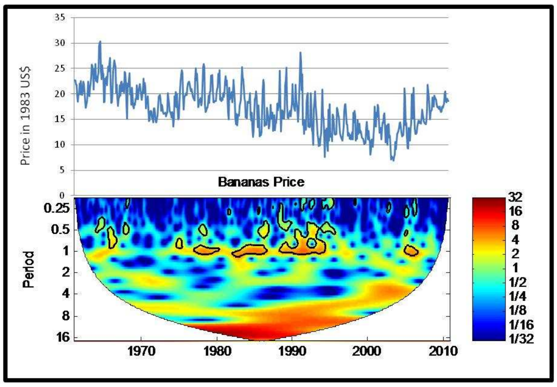
Appendix A Wavelet Analysis Results (Graphs)

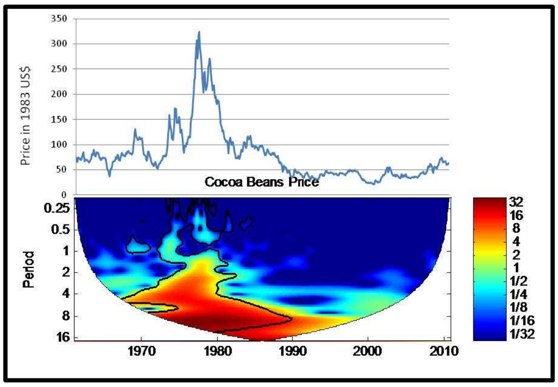
A.1 Continuous Wavelet Transform

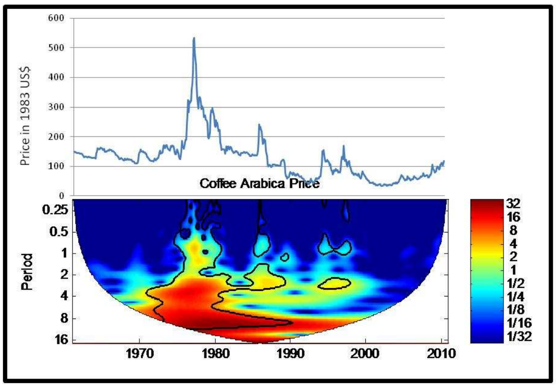


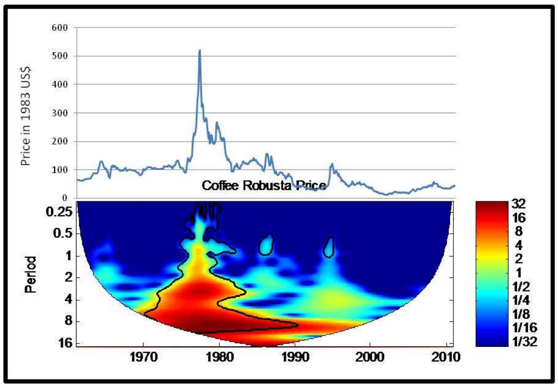


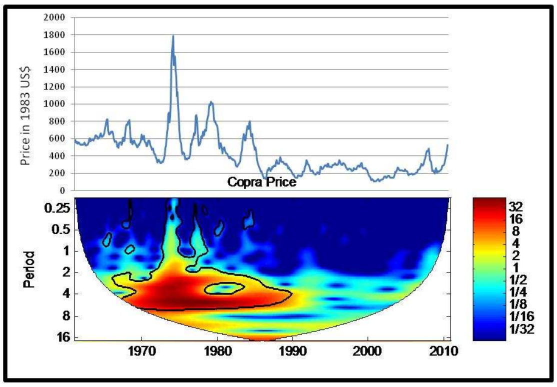


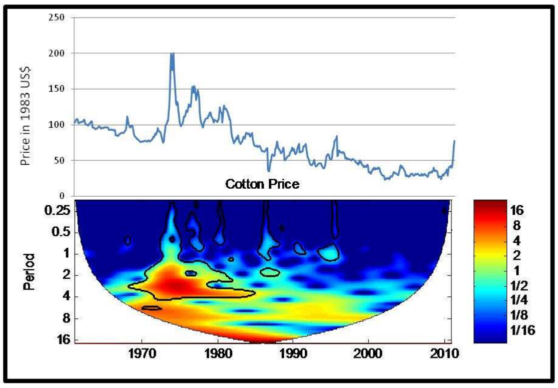


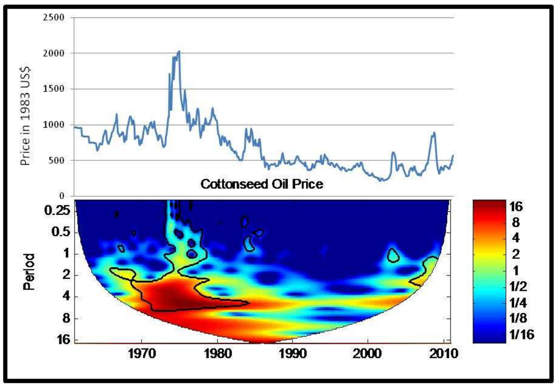


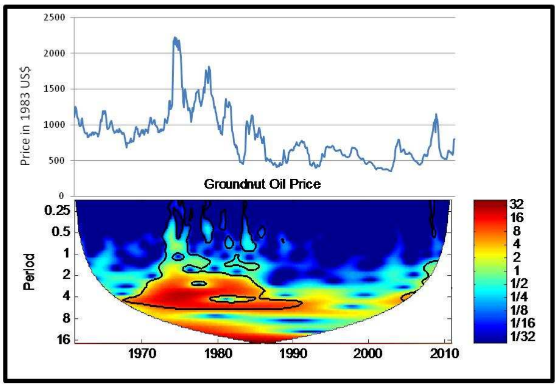

Price in 1983 US$
Coffee Arabica Price
Period
1970
1980
1990
2000
2010

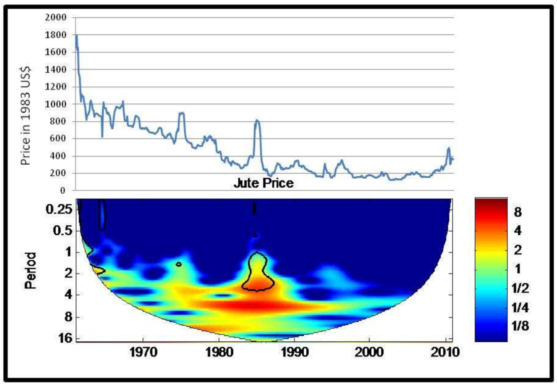

Price in 1983 US$
Coffee Robusta Price
Period
1970
1980
1990
2000
2010


Price in 1983 US$
Copra Price
Period
1970
1980
1990
2000
2010


Price in 1983 US$
Cotton Price
Period
1970
1980
1990
2000
2010


Price in 1983 US$
Cottonseed Oil Price
Period
1970
1980
1990
2000
2010


Price in 1983 US$
Groundnut Oil Price
Period
1970
1980
1990
2000
2010


Price in 1983 US$
Jute Price
Period
1970
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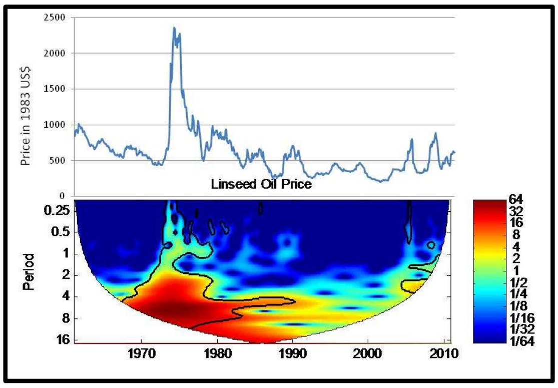
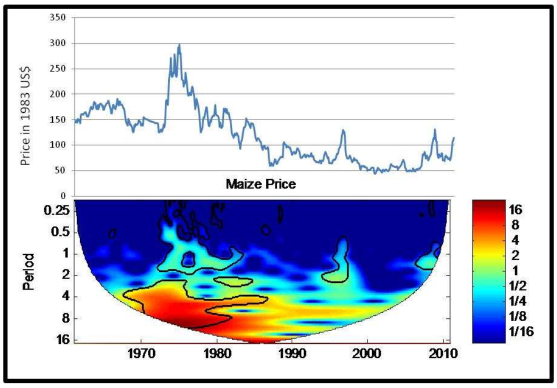
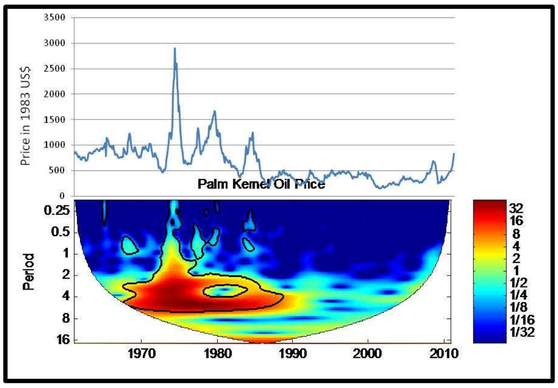
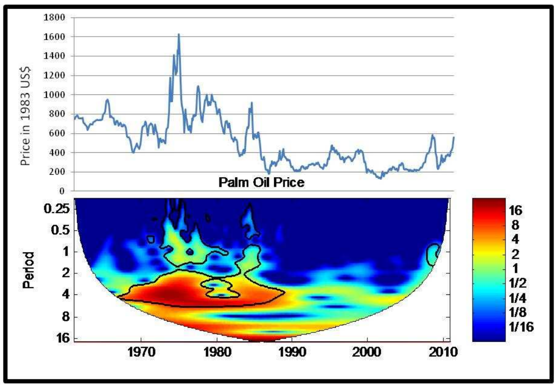
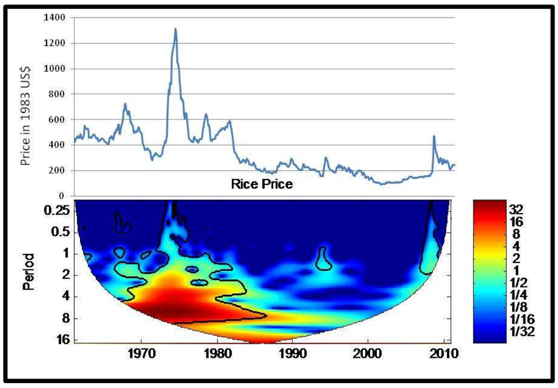

Price in 1983 US$
Linseed Oil Price
Period
1970
1980
1990
2000
2010


Price in 1983 US$
0
50
100
150
200
250
300
350
Maize Price
Period
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
16
8
4
2
1
1/2
1/4
1/8
1/16


Price in 1983 US$
0
500
1000
1500
2000
2500
3000
3500
Palm Kernel Oil Price
Period
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
32
16
8
4
2
1
1/2
1/4
1/8
1/16
1/32


Price in 1983 US$
0
200
400
600
800
1000
1200
1400
1600
1800
Palm Oil Price
Period
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
16
8
4
2
1
1/2
1/4
1/8
1/16


Price in 1983 US$
0
200
400
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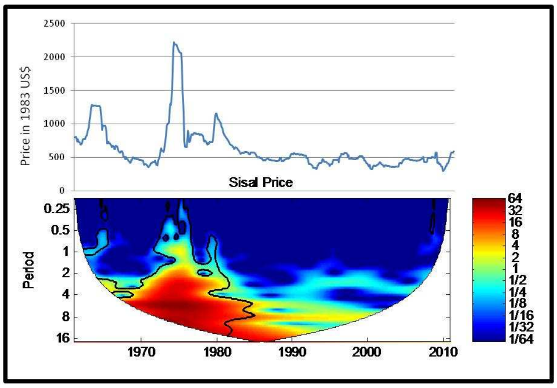
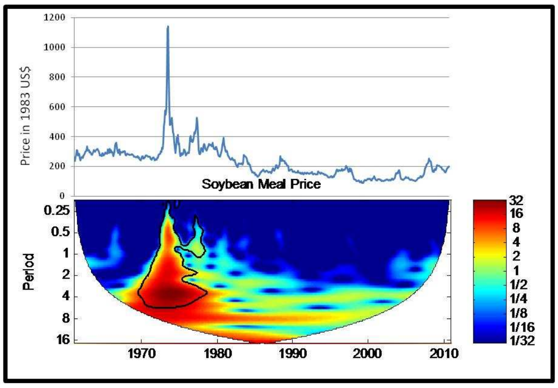
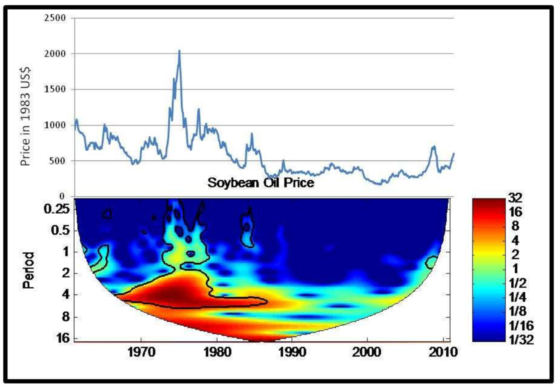
800
1000
1200
1400
Rice Price
Period
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
32
16
8
4
2
1
1/2
1/4
1/8
1/16
1/32


Price in 1983 US$
0
500
1000
1500
2000
2500
Sisal Price
Period
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
64
32
16
8
4
2
1
1/2
1/4
1/8
1/16
1/32
1/64


Price in 1983 US$
0
200
400
600
800
1000
1200
Soybean Meal Price
Period
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
32
16
8
4
2
1
1/2
1/4
1/8
1/16
1/32


Price in 1983 US$
0
500
1000
1500
2000
2500
Soybean Oil Price
Period
0.25
0.5
1
2
4
8
16
1970
1980
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2000
2010
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16
8
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1/2
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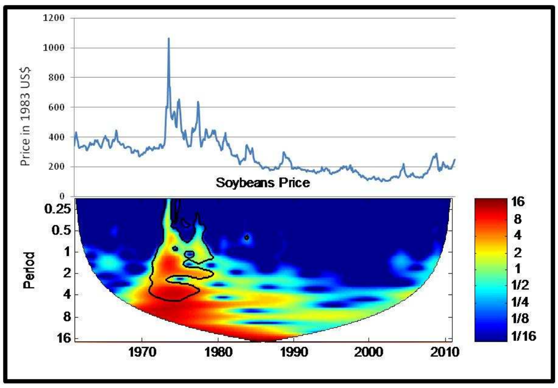
1/8
1/16
1/32


Price in 1983 US$
0
200
400
600
800
1000
1200
Soybeans Price
Period
0.25
0.5
1
2
4
8
16
1970
1980
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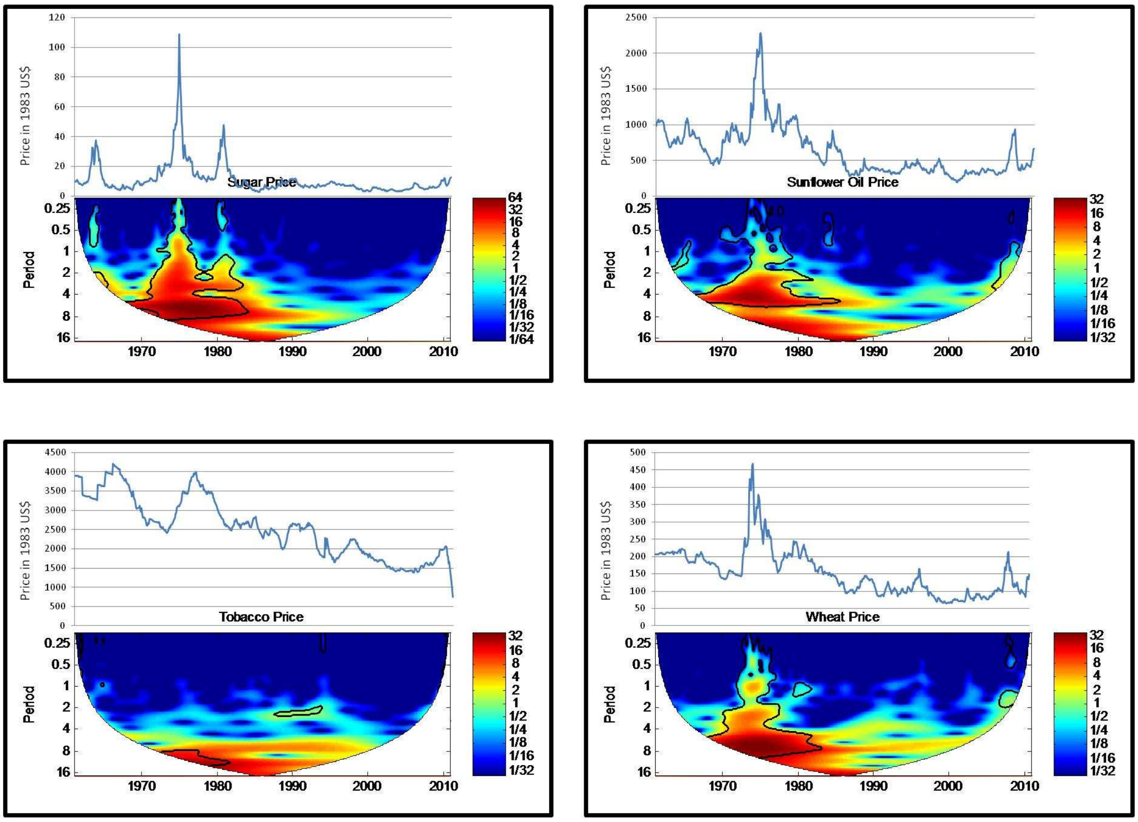
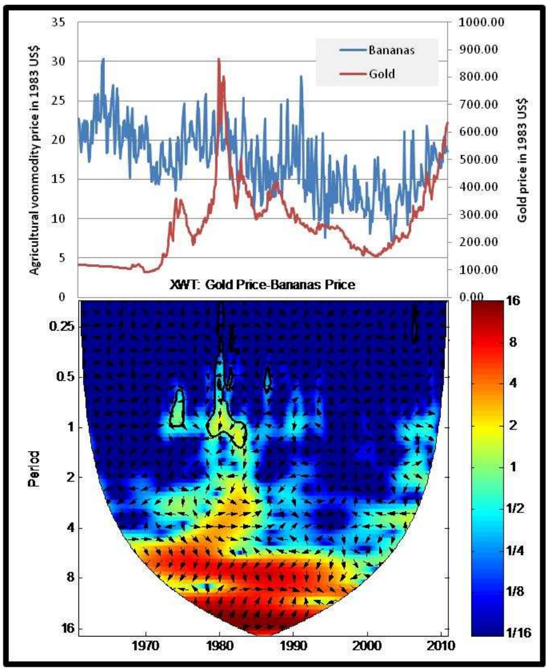
2000
2010
16
8
4
2
1
1/2
1/4
1/8
1/16

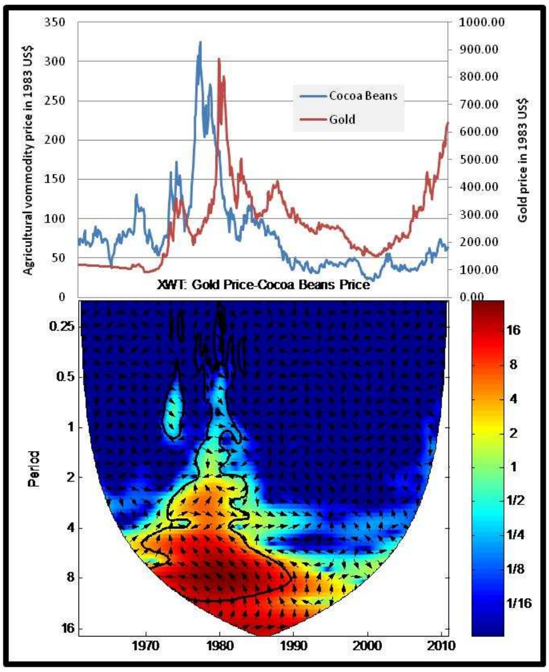


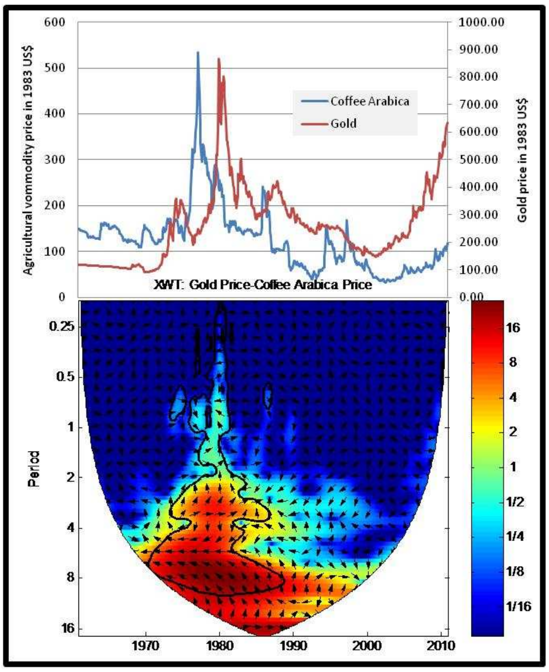
Figure_Apx 1 CWT Results

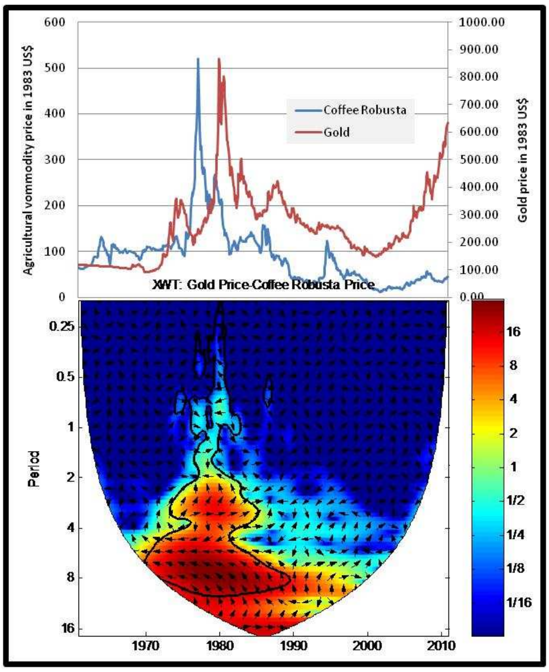
A.2 Cross Wavelet Transform

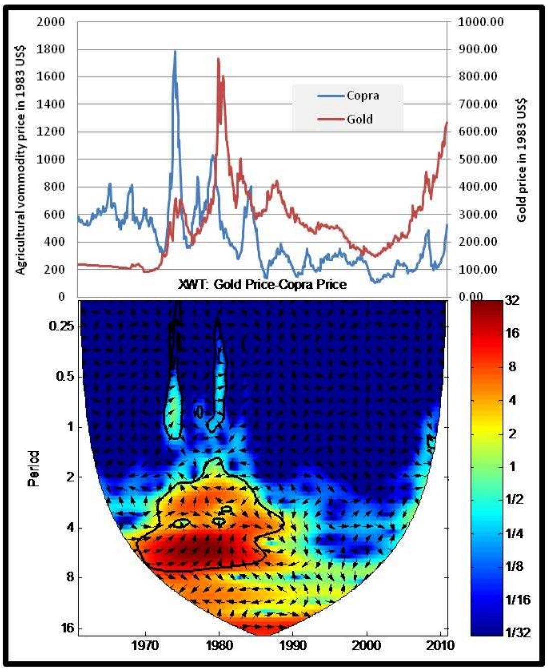
A.2.1 Cross Wavelet Transform – Gold Price

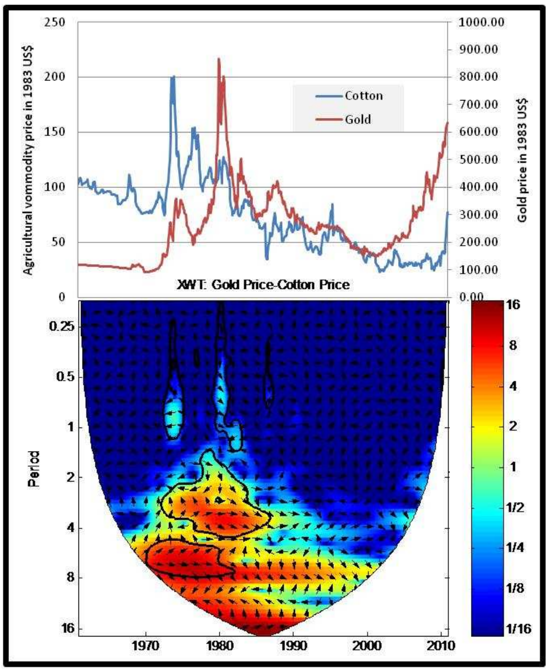


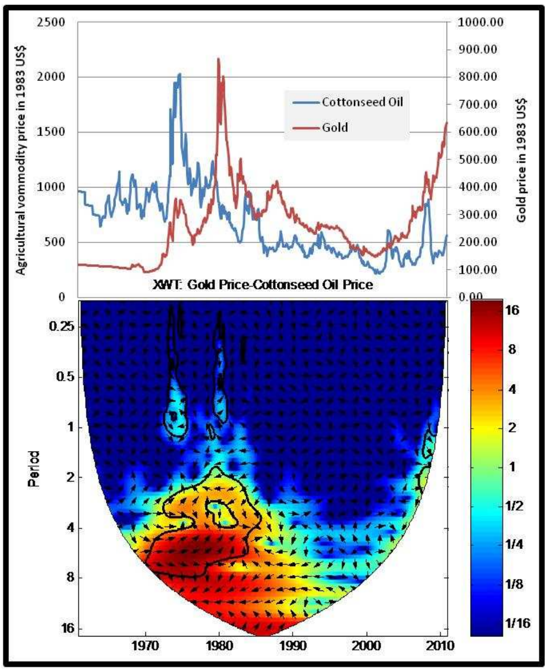


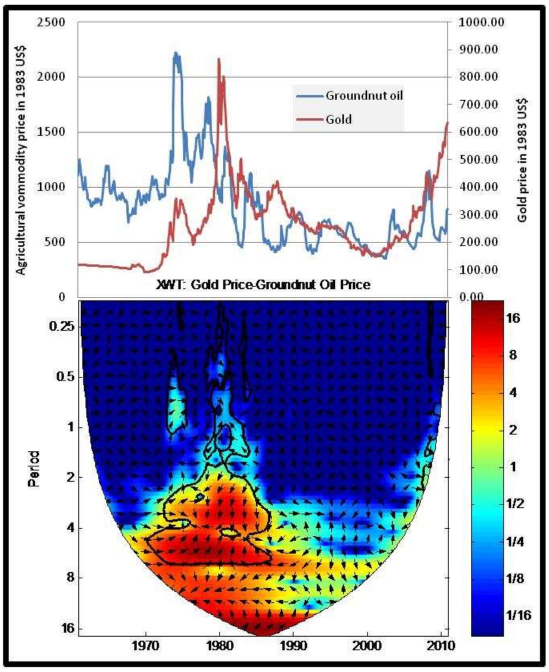


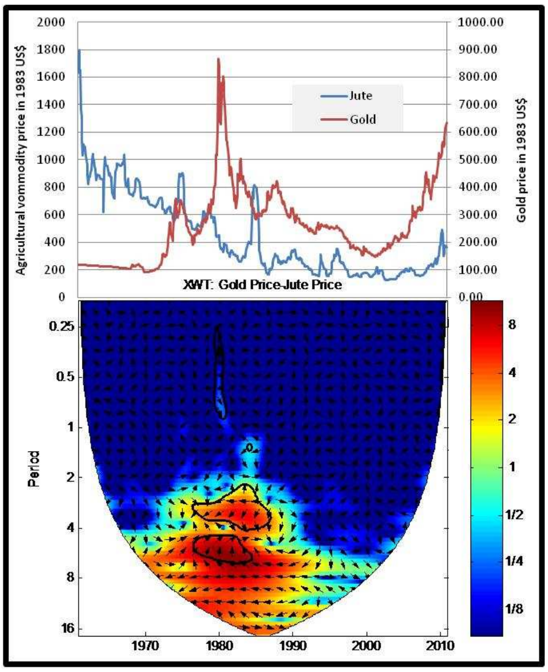


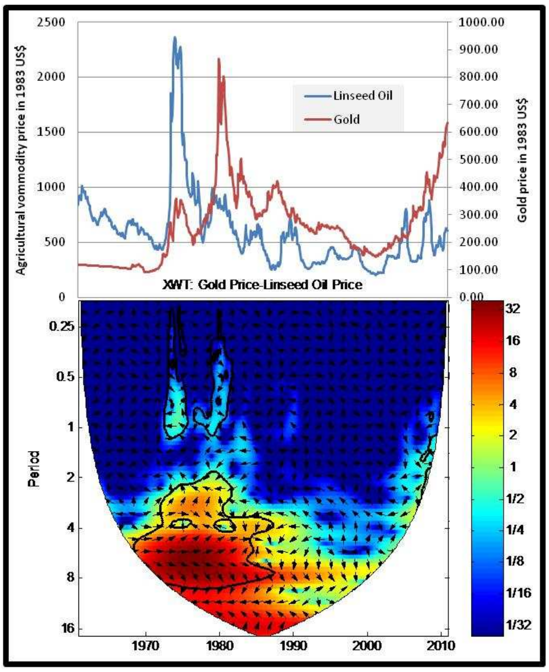

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Copra
Gold
XWT: Gold Price-Copra Price
Period
1970
1980
1990
2000
2010

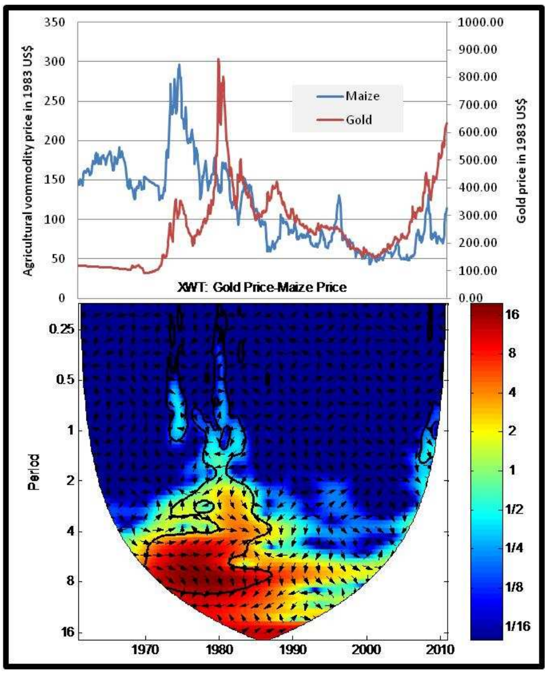

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Cotton
Gold
XWT: Gold Price-Cotton Price
Period
1970
1980
1990
2000
2010

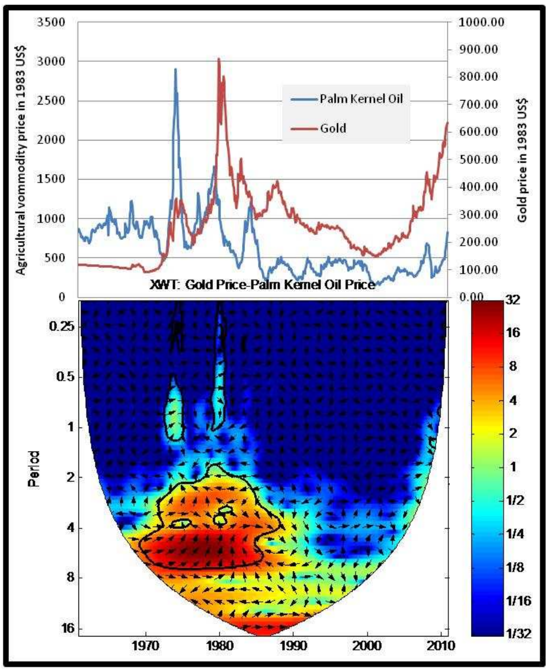

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Cottonseed Oil
Gold
XWT: Gold Price-Cottonseed Oil Price
Period
1970
1980
1990
2000
2010

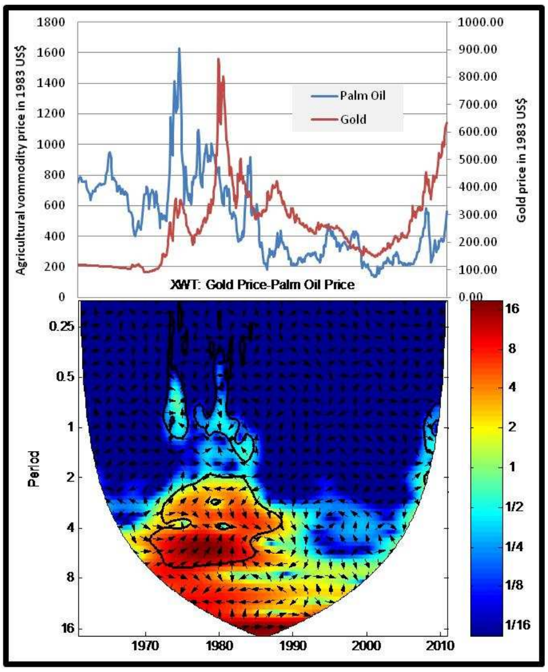

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Groundnut oil
Gold
XWT: Gold Price-Groundnut Oil Price
Period
1970
1980
1990
2000
2010

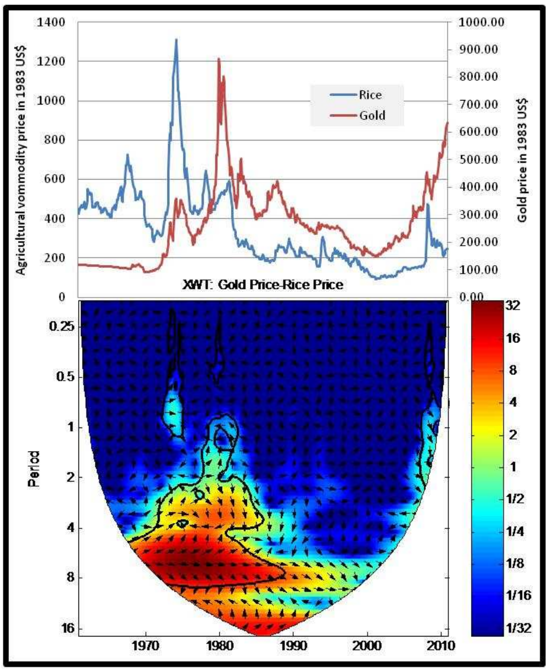

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Jute
Gold
XWT: Gold Price-Jute Price
Period

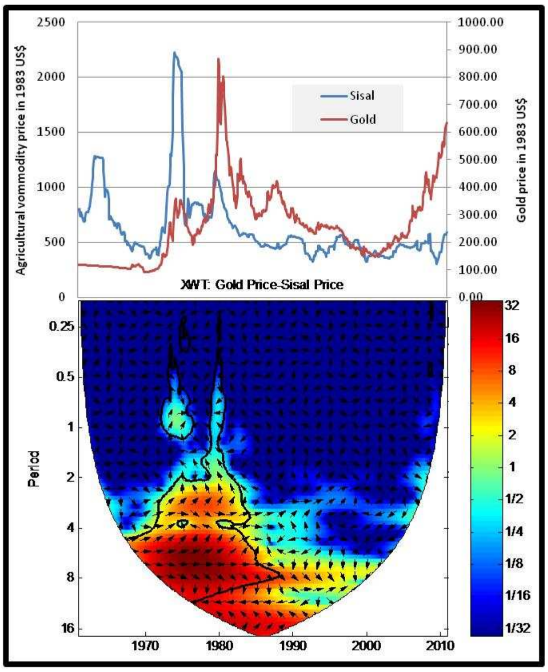

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Linseed Oil
Gold
XWT: Gold Price-Linseed Oil Price
Period

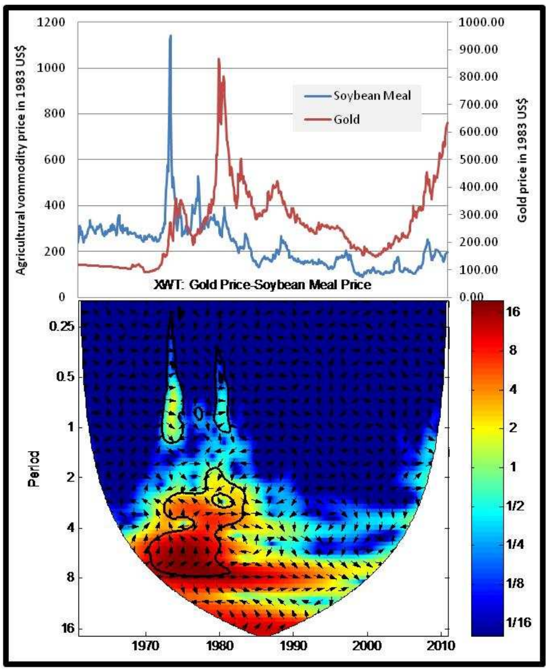

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Maize
Gold
XWT: Gold Price-Maize Price
Period

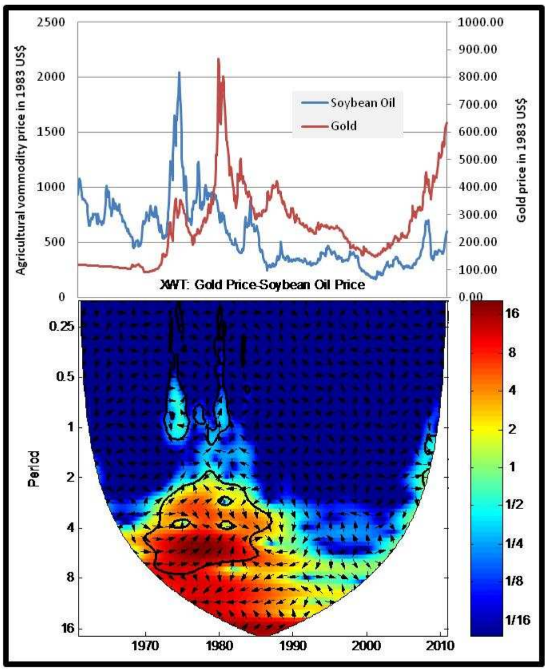

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Palm Kernel Oil
Gold
XWT: Gold Price-Palm Kernel Oil Price
Period

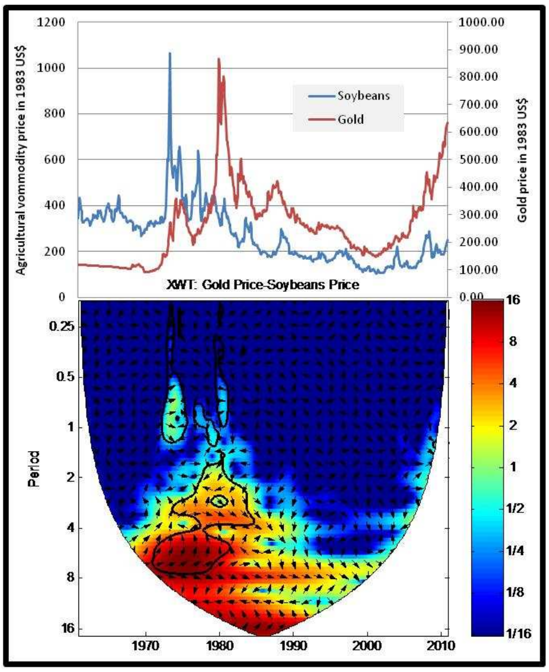

Palm Oil
Gold
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
XWT: Gold Price-Palm Oil Price
Period

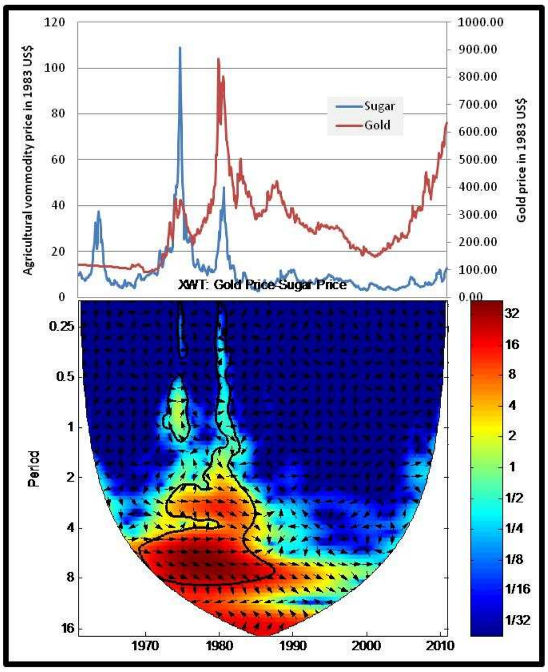

Rice
Gold
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
XWT: Gold Price-Rice Price
Period

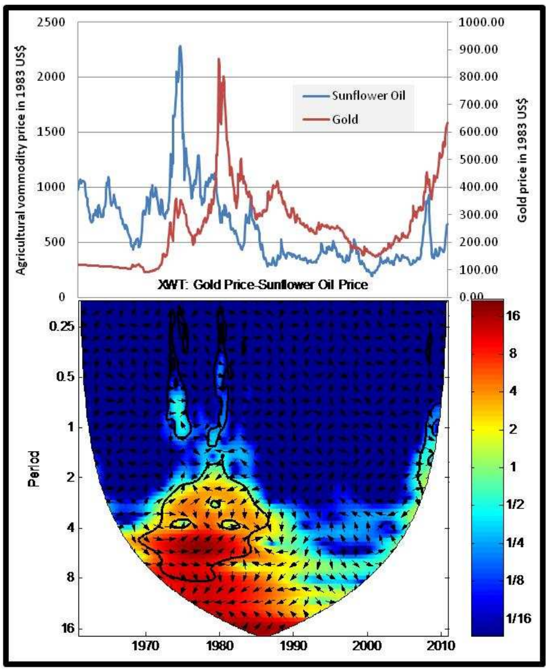

Sisal
Gold
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
XWT: Gold Price-Sisal Price
Period

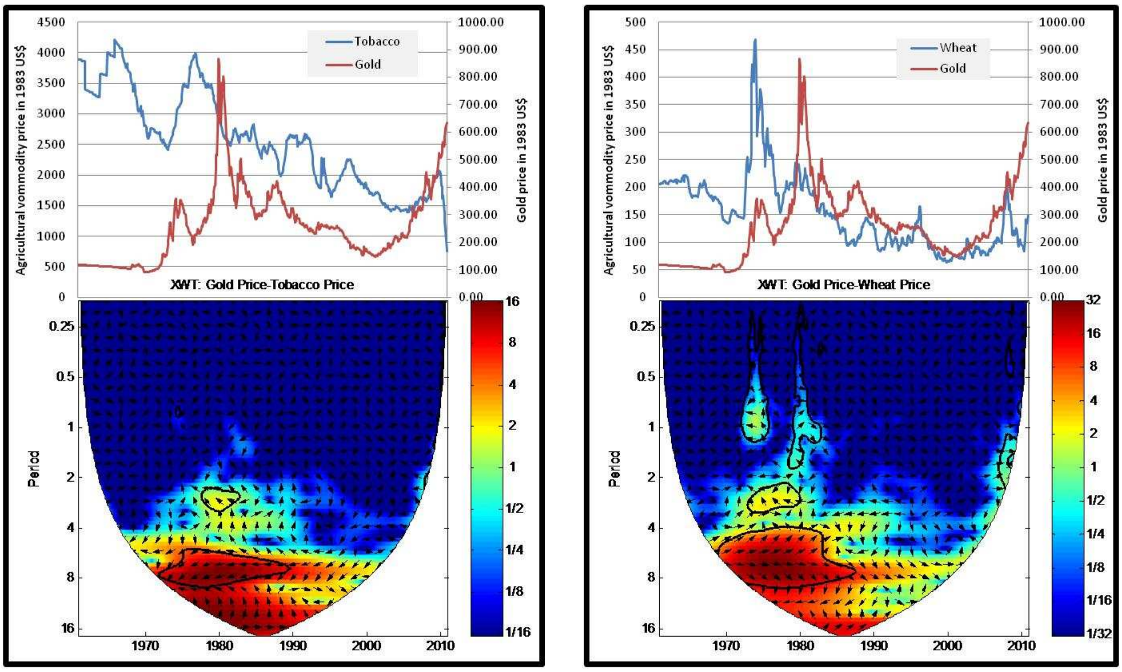

Soybean Meal
Gold
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
XWT: Gold Price-Soybean Meal Price
Period


Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Soybean Oil
Gold
XWT: Gold Price-Soybean Oil Price
Period


Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Soybeans
Gold
XWT: Gold Price-Soybeans Price
Period

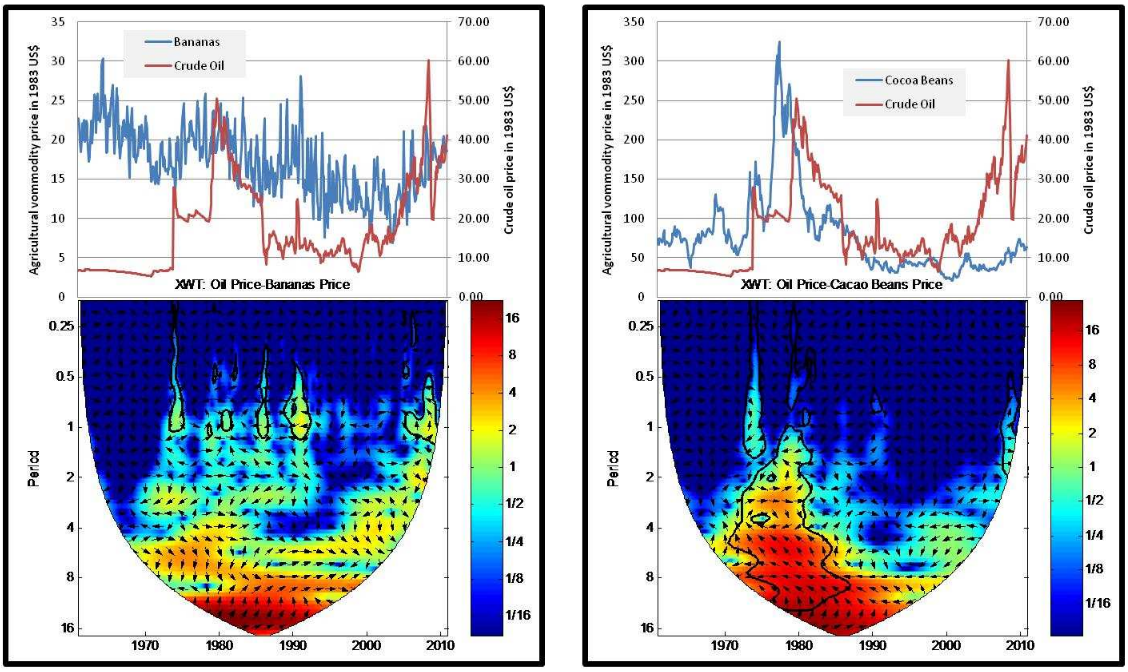

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Sugar
Gold
XWT: Gold Price-Sugar Price
Period

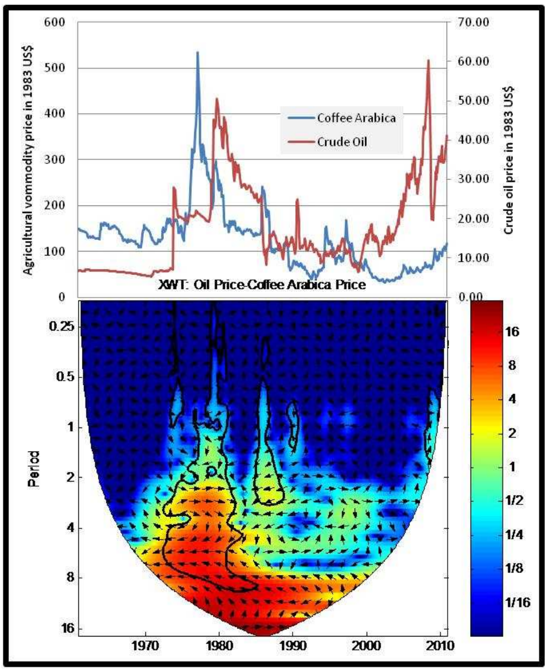

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Sunflower Oil
Gold
XWT: Gold Price-Sunflower Oil Price
Period

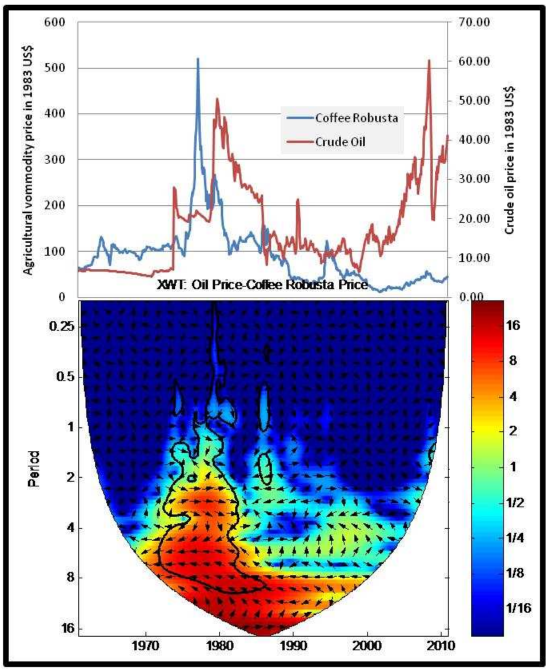


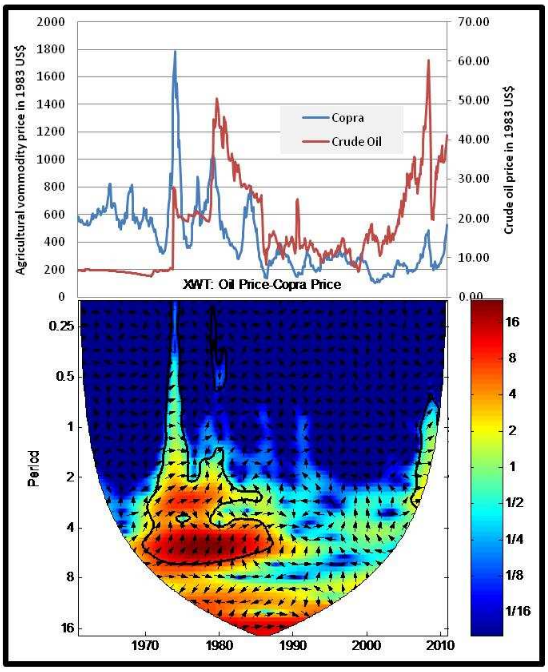
Figure_Apx 2 XWT Results – Gold Price

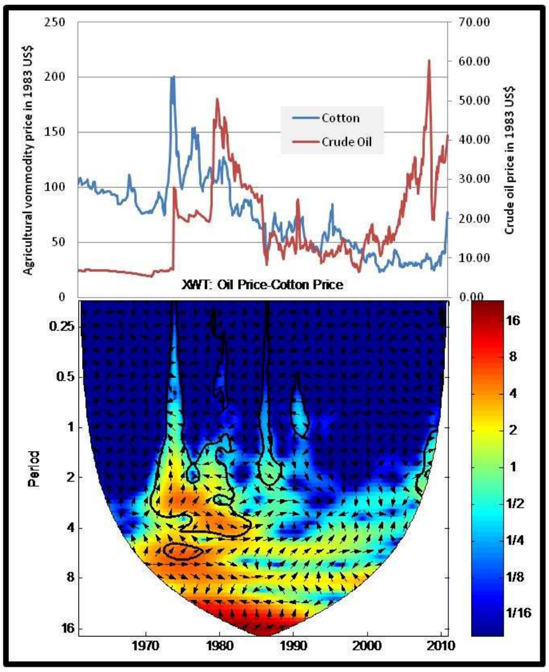
A.2.2 Cross Wavelet Transform – Crude oil Price

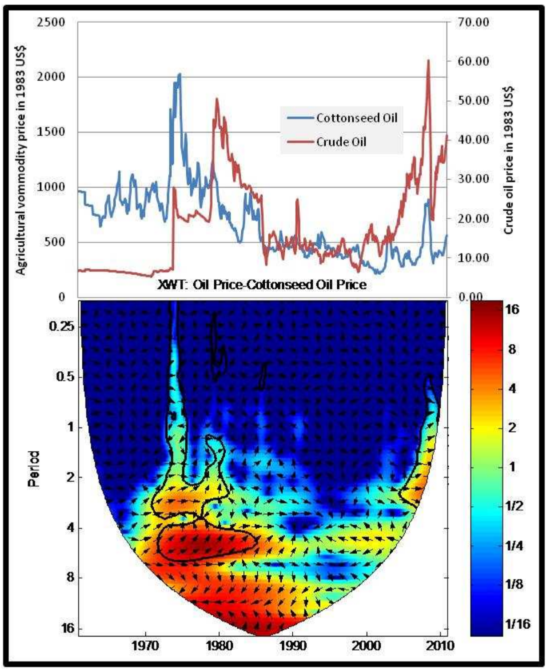


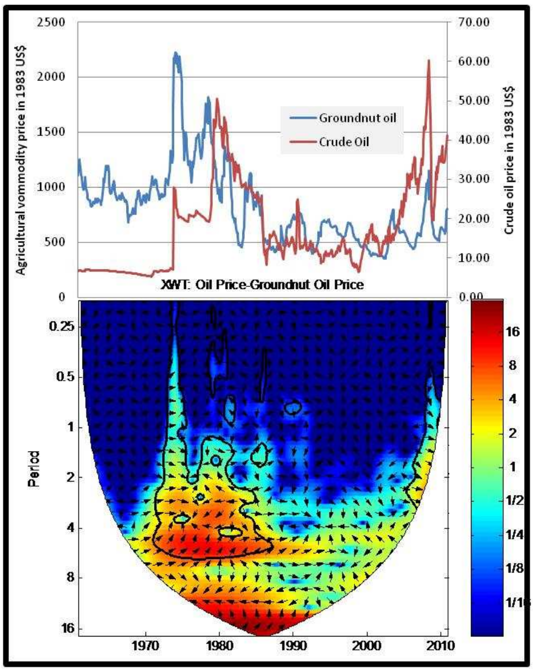

Coffee Arabica
Crude Oil
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
XWT: Oil Price-Coffee Arabica Price
Period

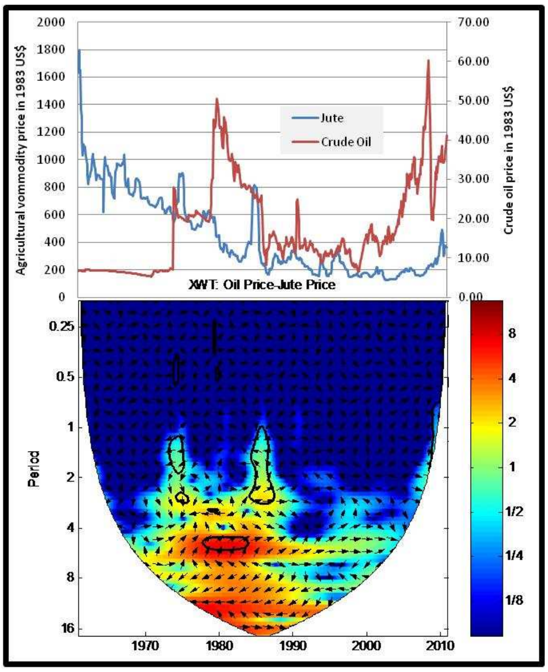

Coffee Robusta
Crude Oil
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
XWT: Oil Price-Coffee Robusta Price
Period

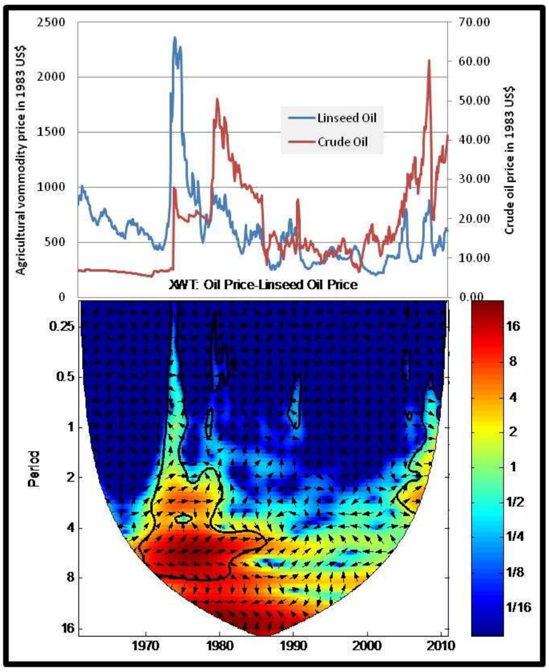

Copra
Crude Oil
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
XWT: Oil Price-Copra Price
Period

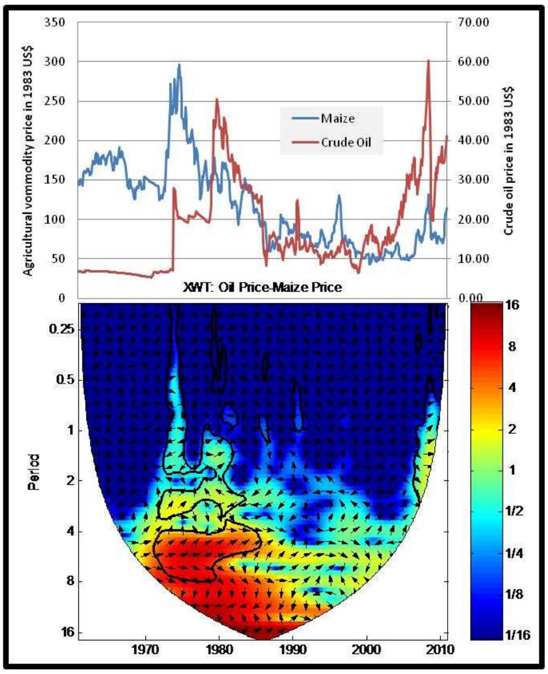

Cotton
Crude Oil
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
XWT: Oil Price-Cotton Price
Period

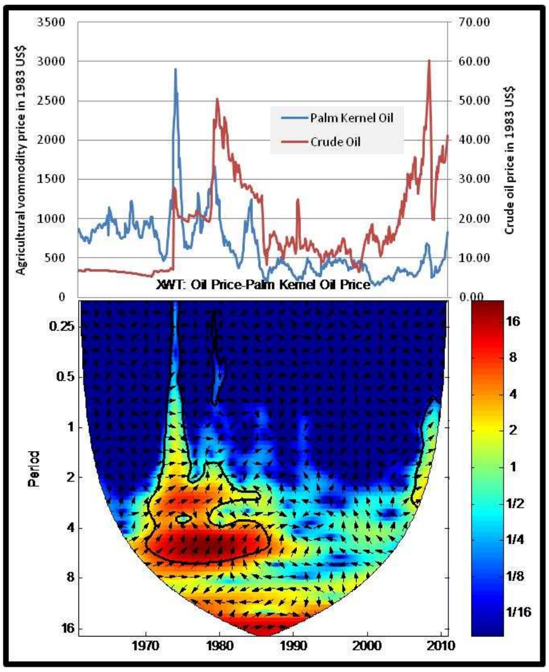

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Cottonseed Oil
Crude Oil
XWT: Oil Price-Cottonseed Oil Price
Period
1970
1980
1990
2000
2010

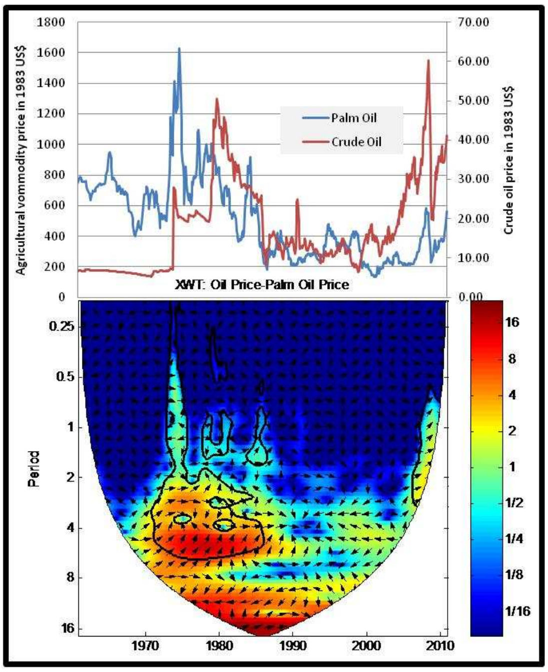

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Groundnut oil
Crude Oil
XWT: Oil Price-Groundnut Oil Price
Period
1970
1980
1990
2000
2010

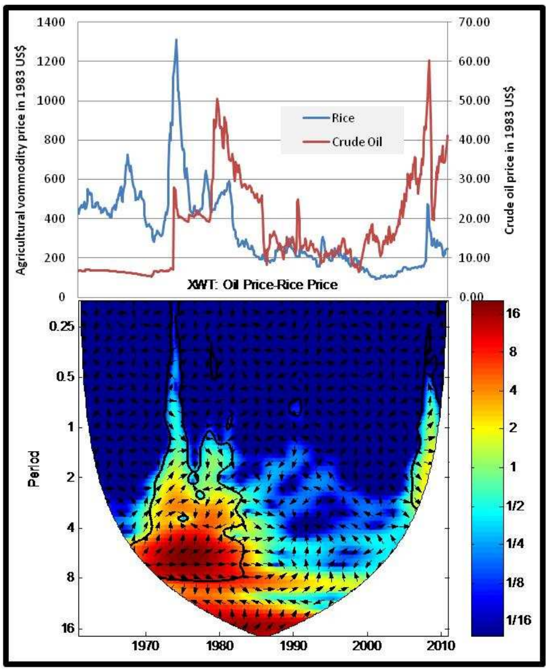

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Jute
Crude Oil
XWT: Oil Price-Jute Price
Period
1970
1980
1990
2000
2010

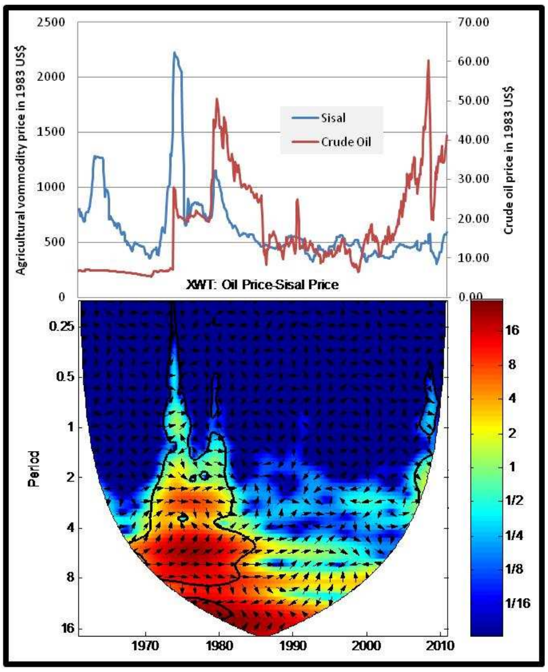

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Linseed Oil
Crude Oil
XWT: Oil Price-Linseed Oil Price
Period
1970
1980
1990
2000
2010

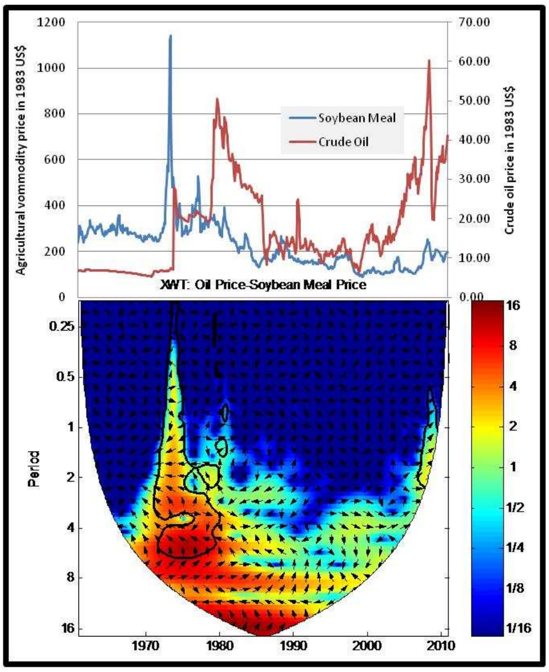

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Maize
Crude Oil
XWT: Oil Price-Maize Price
Period
350
300
250
200
150
100
50
0
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
16
8
4
2
1
1/2
1/4
1/8
1/16

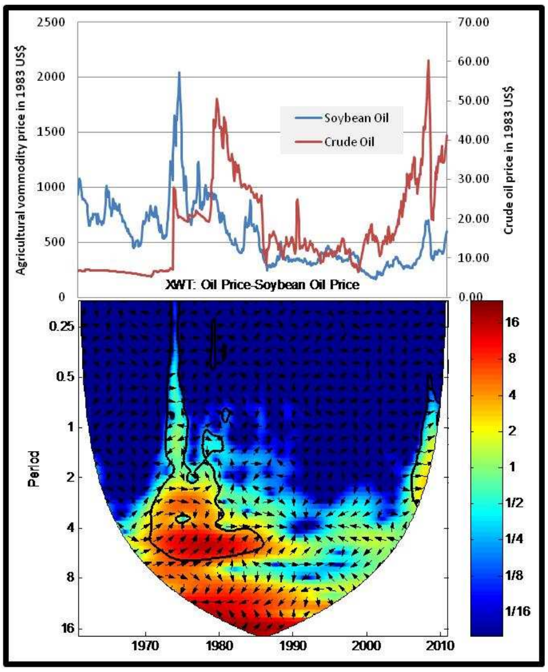

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Palm Kernel Oil
Crude Oil
XWT: Oil Price-Palm Kernel Oil Price
Period
3500
3000
2500
2000
1500
1000
500
0
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
16
8
4
2
1
1/2
1/4
1/8
1/16

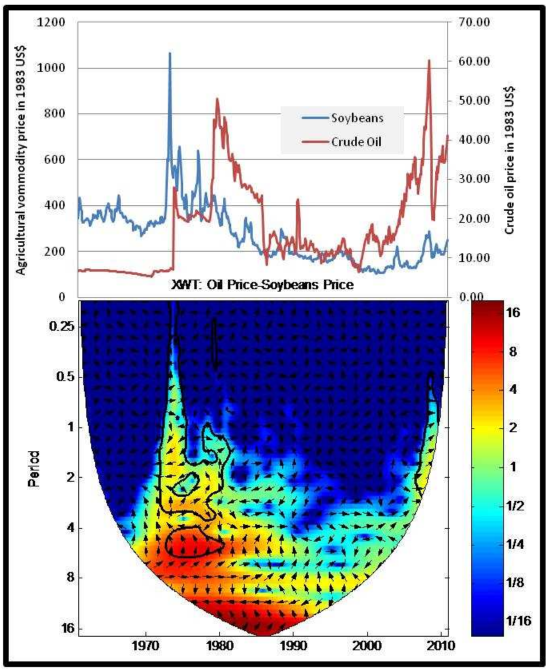

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Palm Oil
Crude Oil
XWT: Oil Price-Palm Oil Price
Period
1800
1600
1400
1200
1000
800
600
400
200
0
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
16
8
4
2
1
1/2
1/4
1/8
1/16

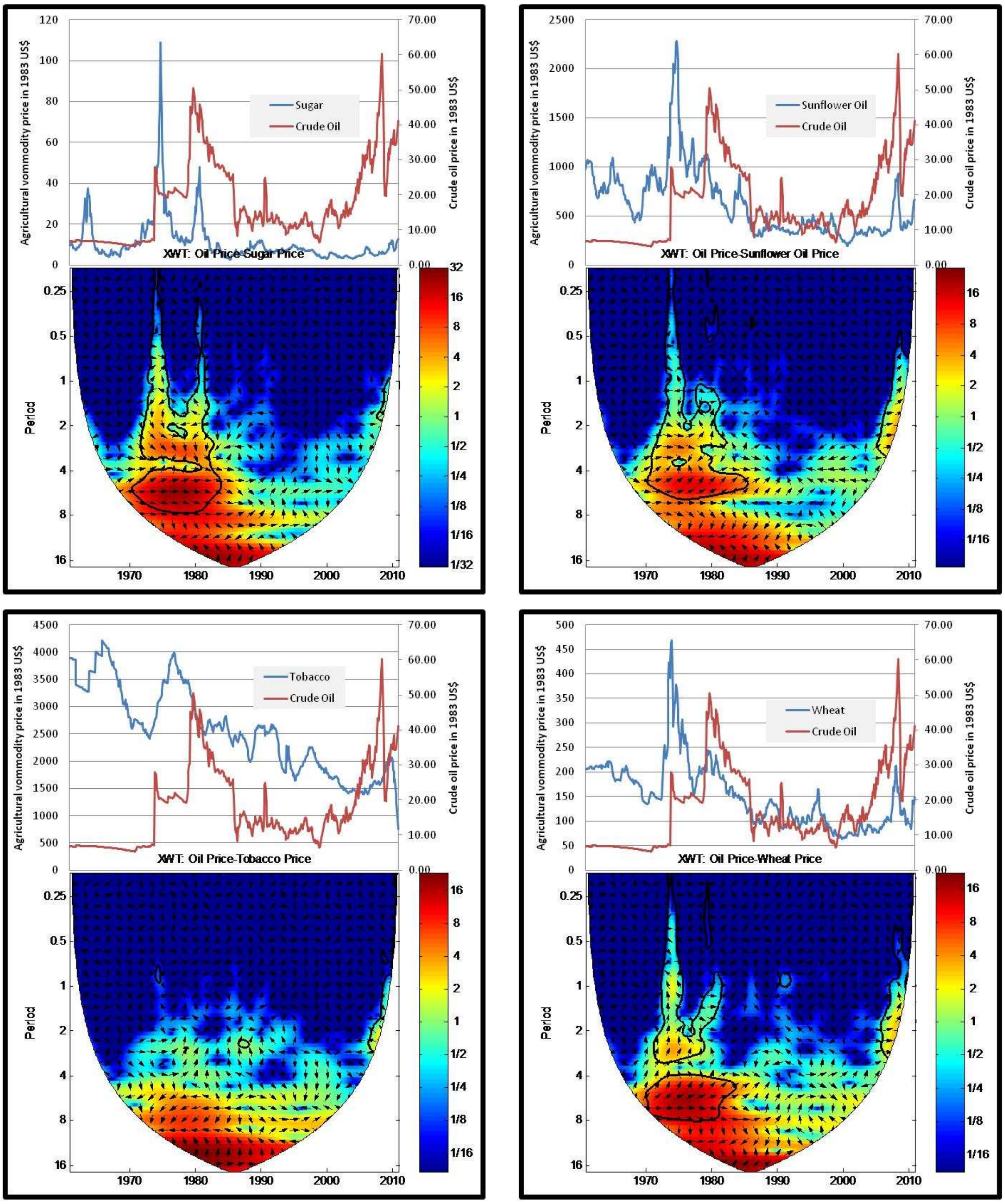

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Rice
Crude Oil
XWT: Oil Price-Rice Price
Period
1400
1200
1000
800
600
400
200
0
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.25
0.5
1
2
4
8
16
1970
1980
1990
2000
2010
16
8
4
2
1
1/2
1/4
1/8
1/16


Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Sisal
Crude Oil
XWT: Oil Price-Sisal Price
Period


Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Soybean Meal
Crude Oil
XWT: Oil Price-Soybean Meal Price
Period

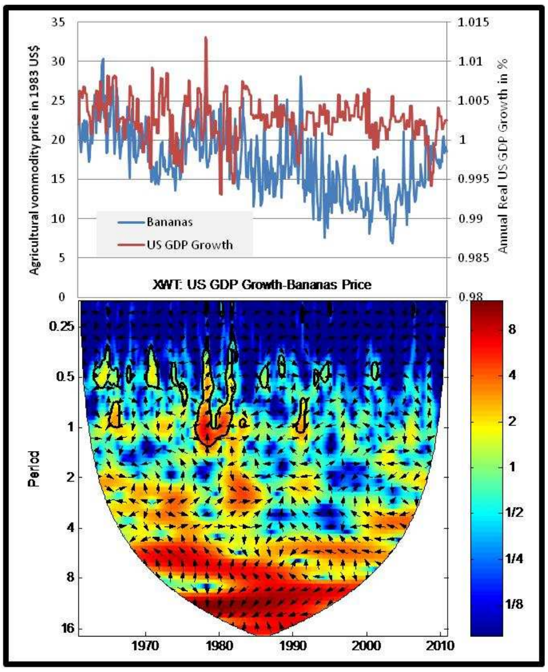

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Soybean Oil
Crude Oil
XWT: Oil Price-Soybean Oil Price
Period

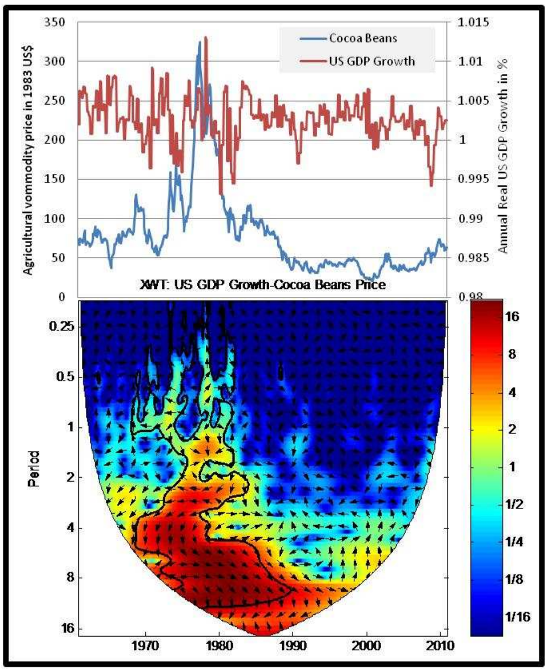

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Soybeans
Crude Oil
XWT: Oil Price-Soybeans Price
Period

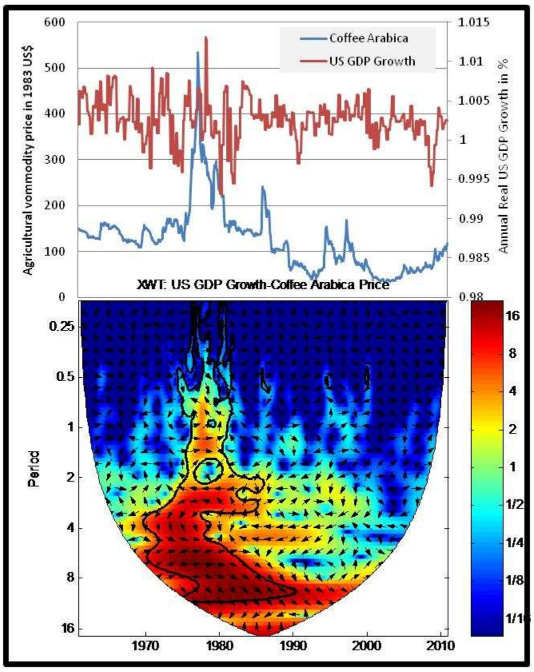


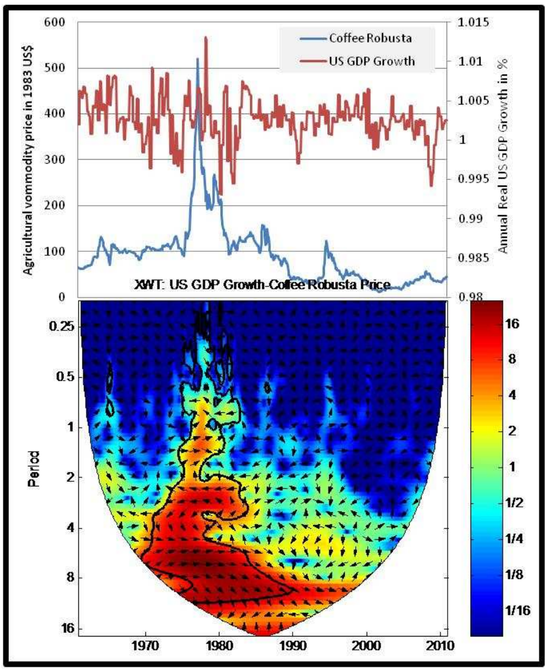
Figure_Apx 3 XWT Results – Crude oil Price

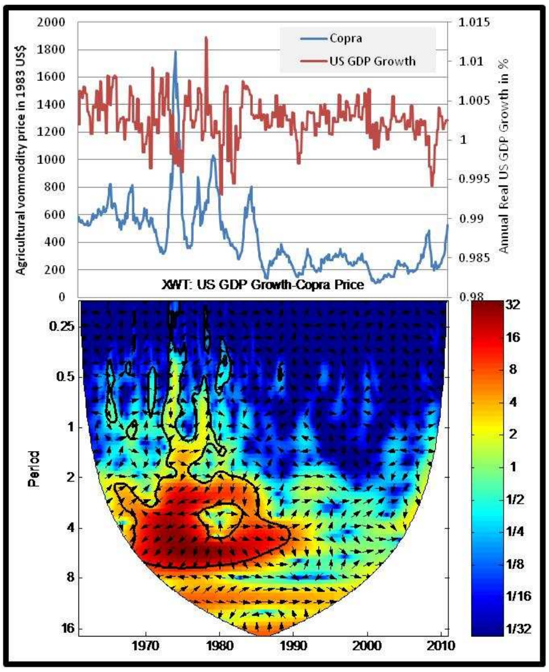
A.2.3 Cross Wavelet Transform – US GDP Growth

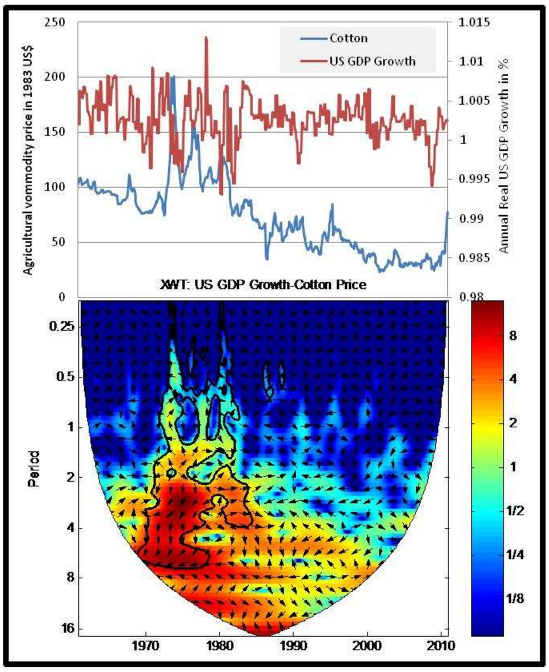


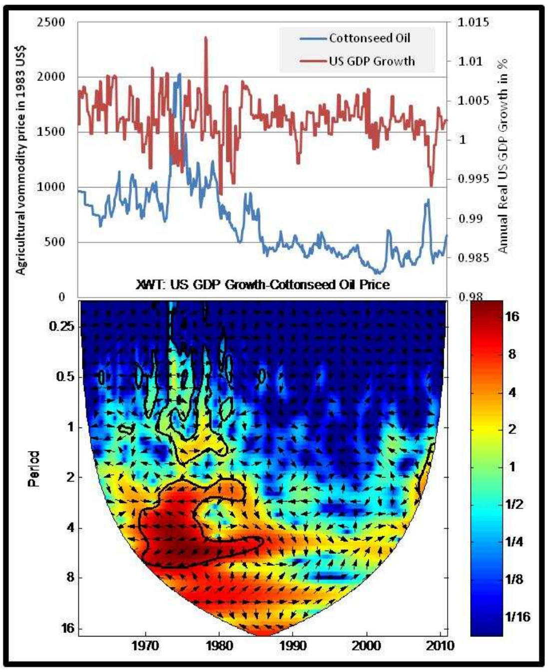


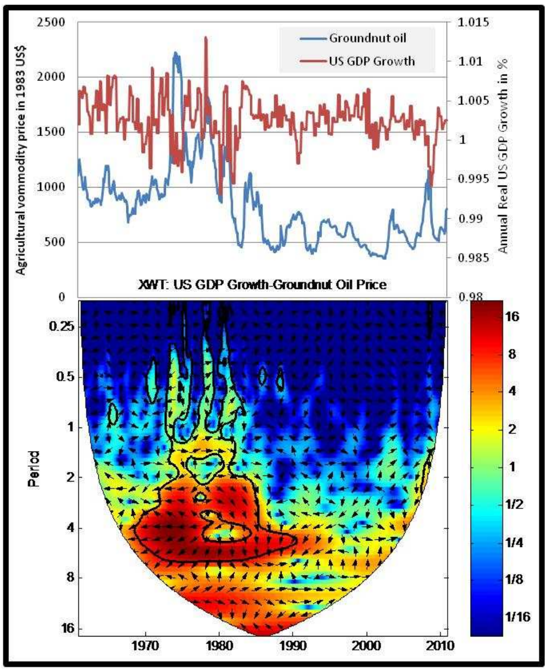


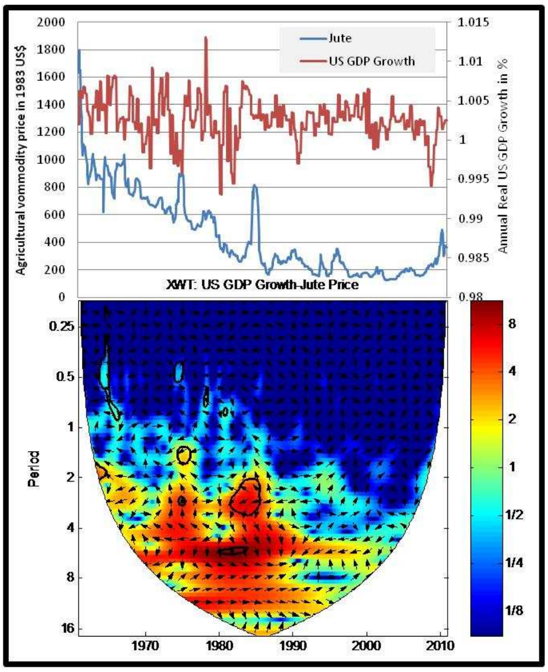


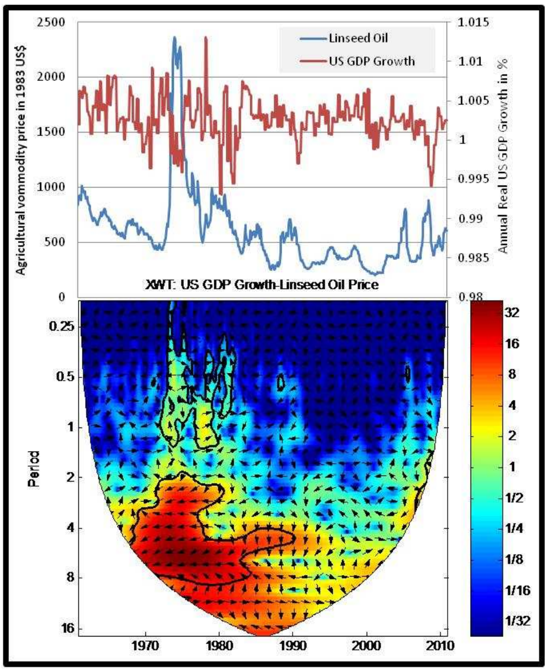

Copra
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Copra Price
Period

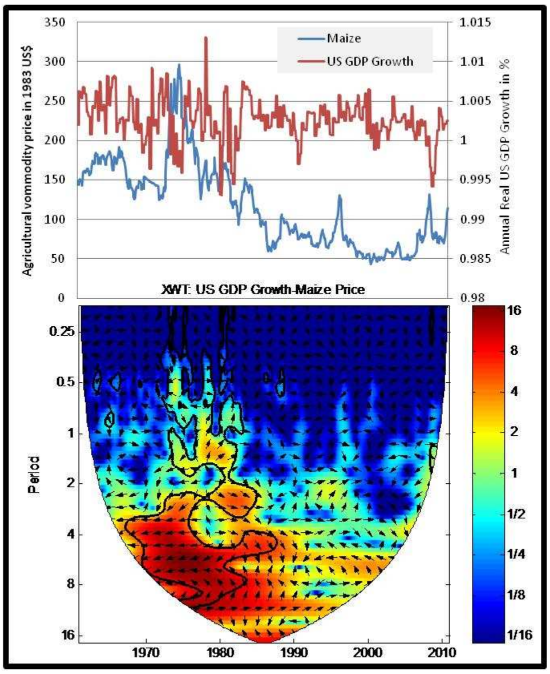

Cotton
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Cotton Price
Period

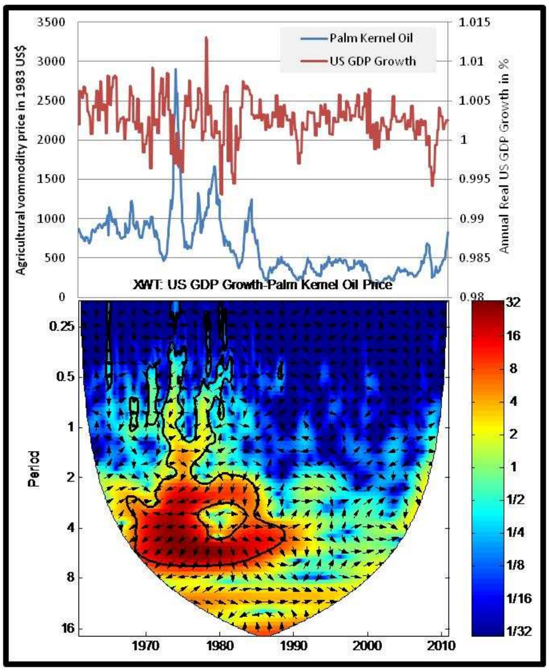

Cottonseed Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Cottonseed Oil Price
Period

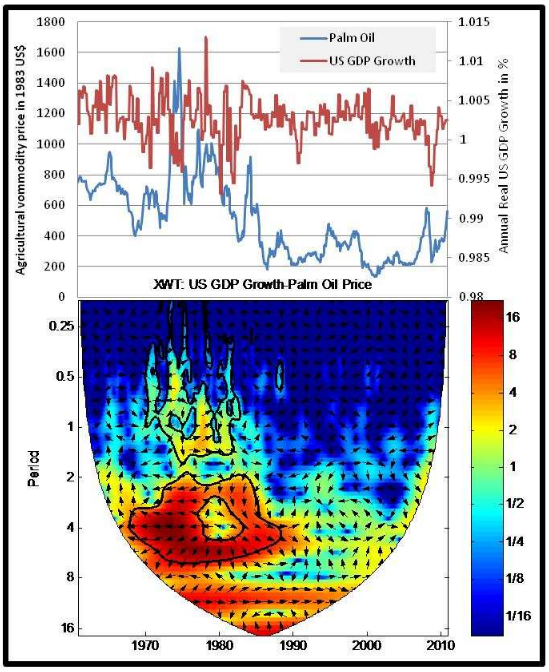

Groundnut oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Groundnut Oil Price
Period

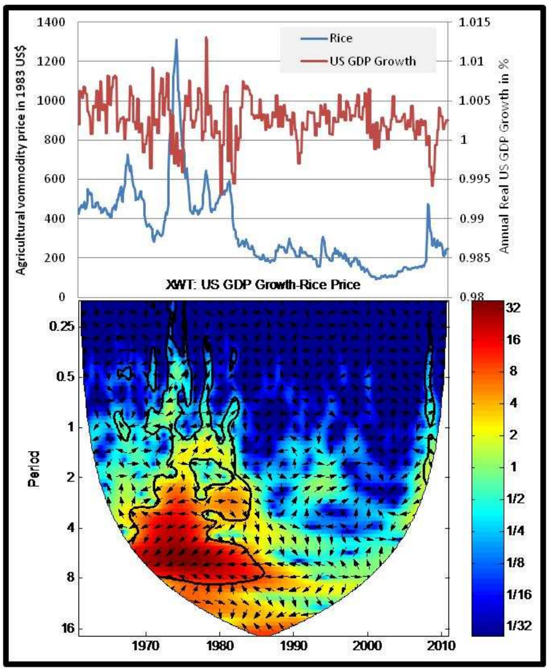

Jute
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Jute Price
Period

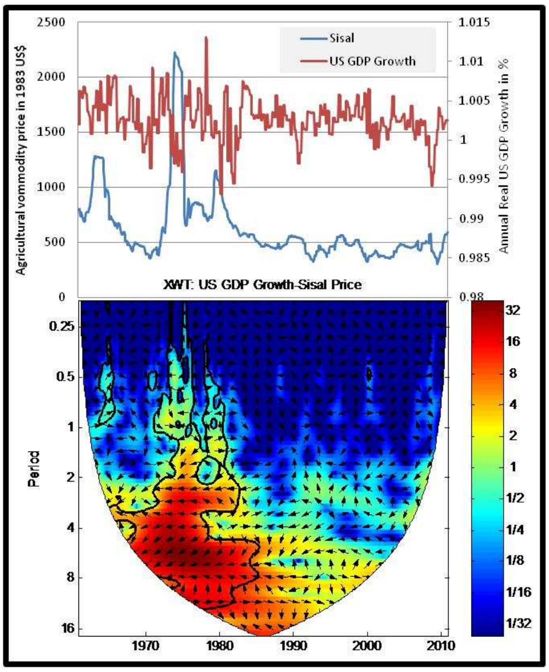

Linseed Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Linseed Oil Price
Period

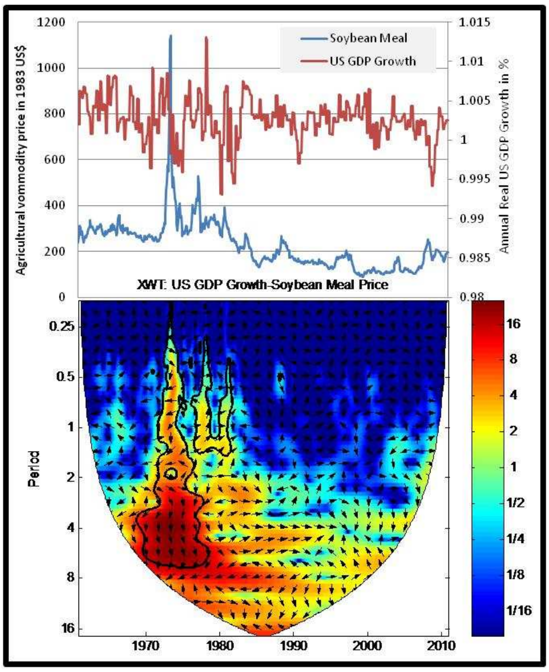

Maize
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Maize Price
Period

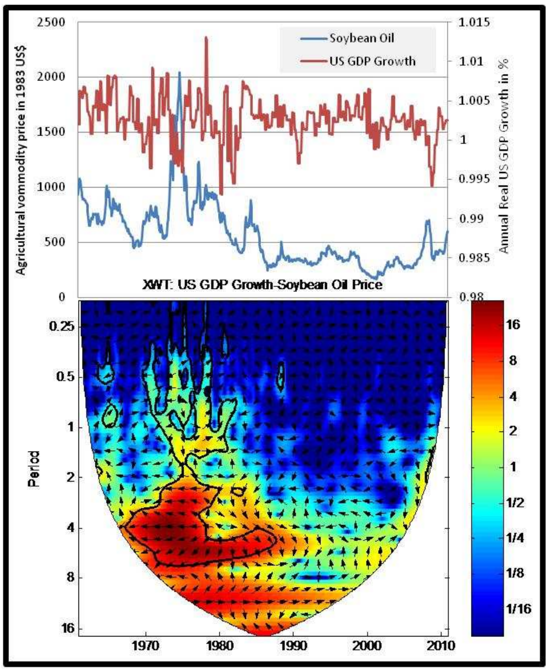

Palm Kernel Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Palm Kernel Oil Price
Period

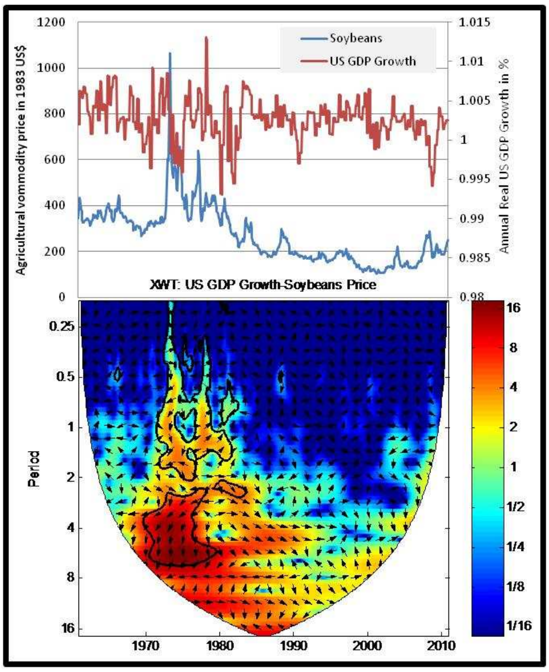

Palm Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Palm Oil Price
Period

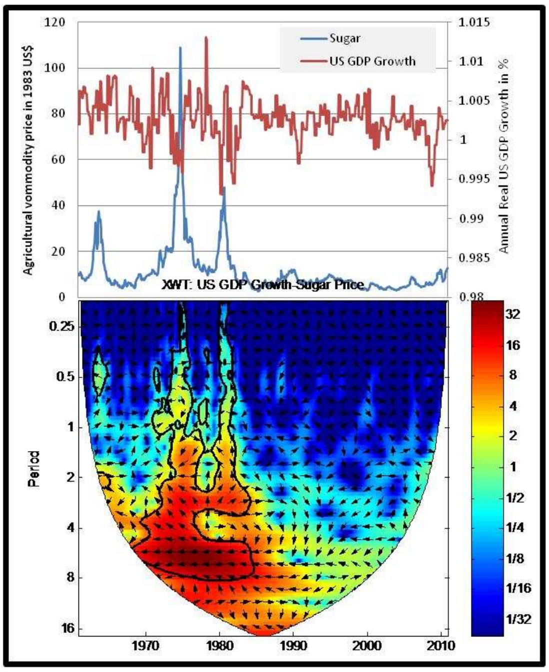

Rice
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Rice Price
Period

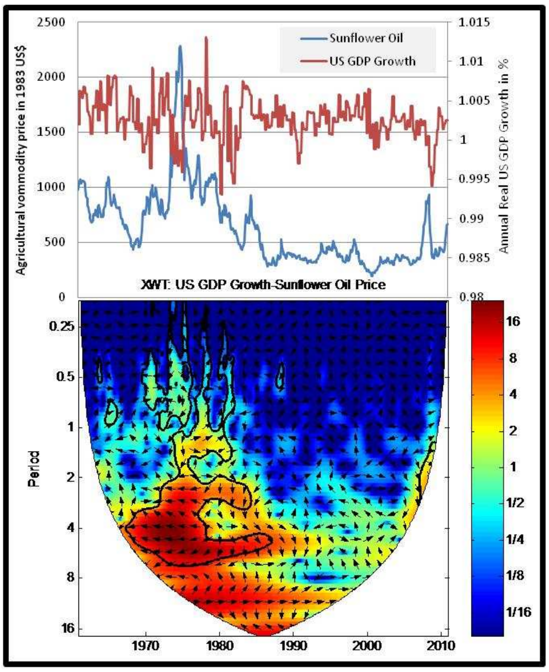

Sisal
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Sisal Price
Period

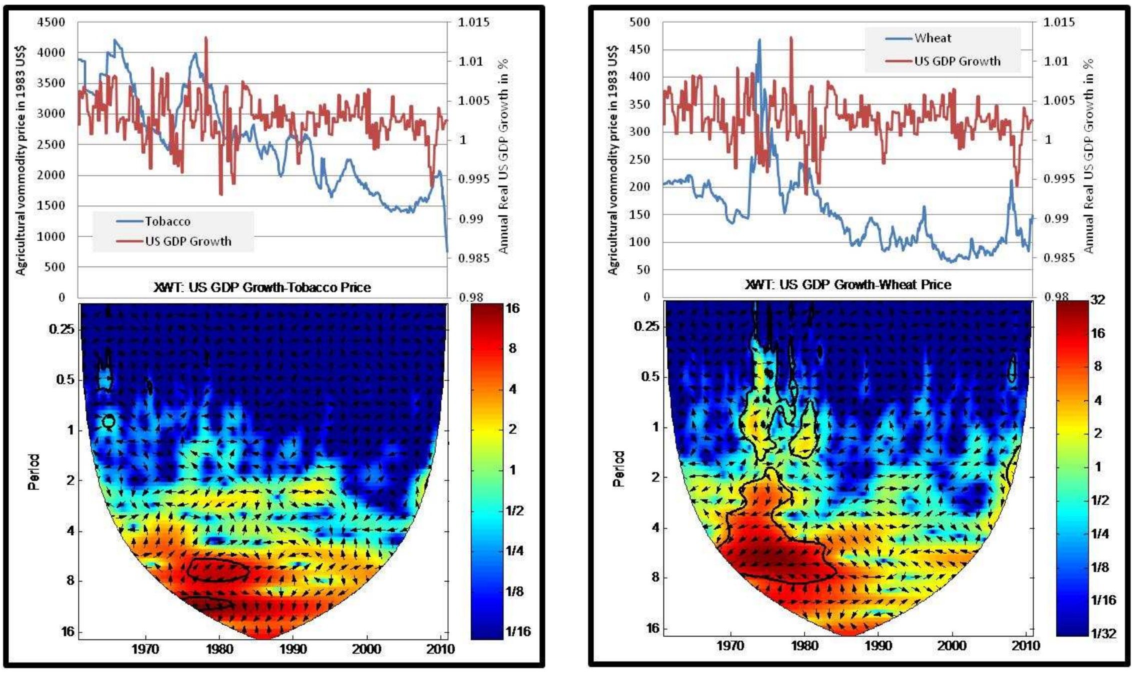

Soybean Meal
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Soybean Meal Price
Period


Soybean Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Soybean Oil Price
Period


Soybeans
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Soybeans Price
Period


Sugar
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Sugar Price
Period

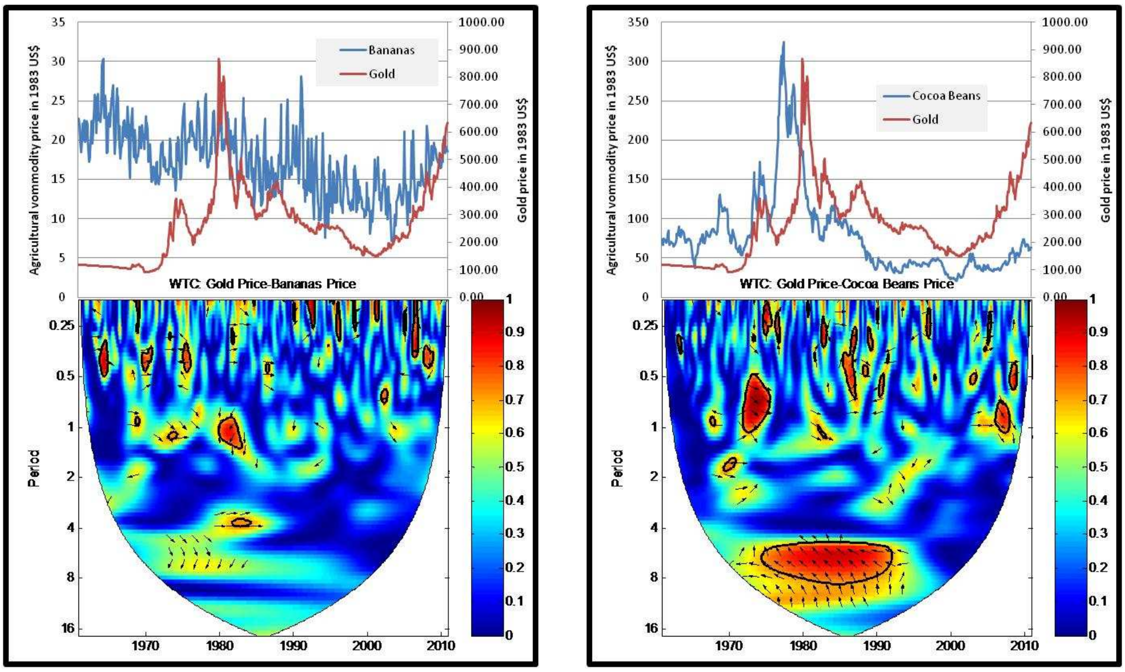

Sunflower Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
XWT: US GDP Growth-Sunflower Oil Price
Period

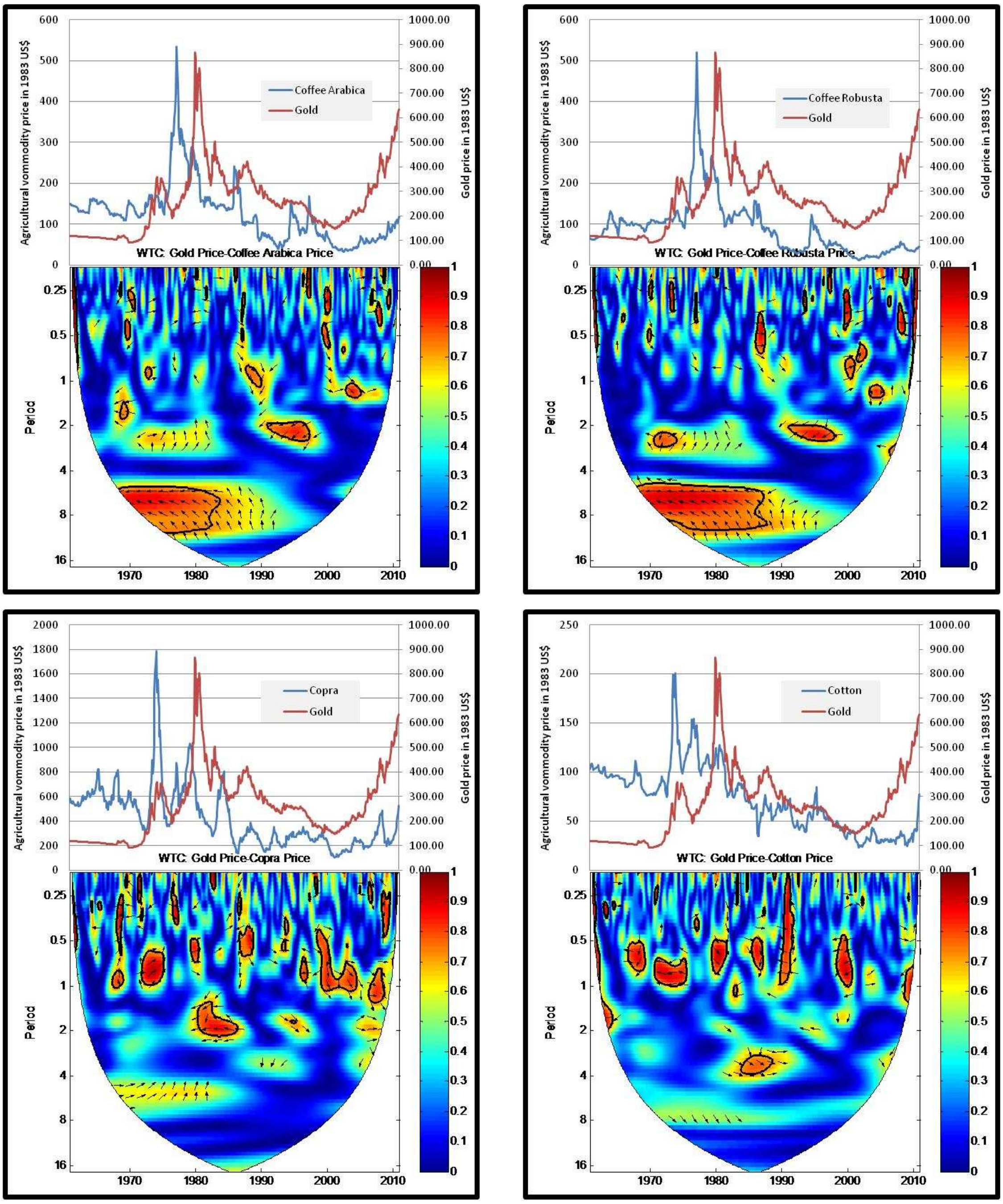


Figure_Apx 4 XWT Results – US GDP Growth

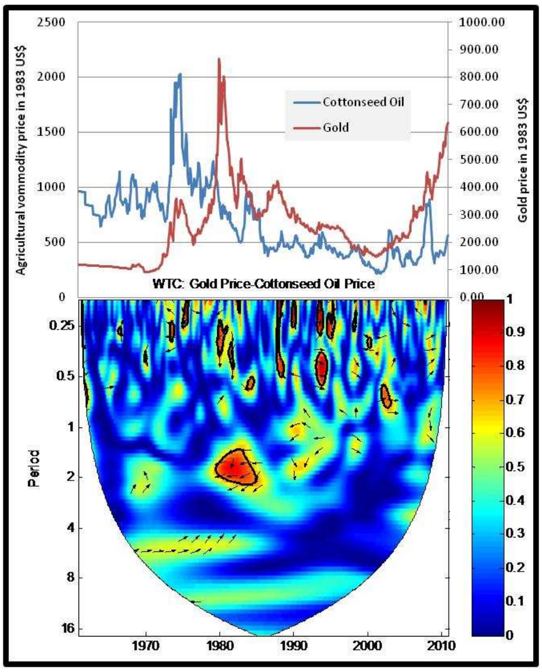
A.3 Wavelet Coherence

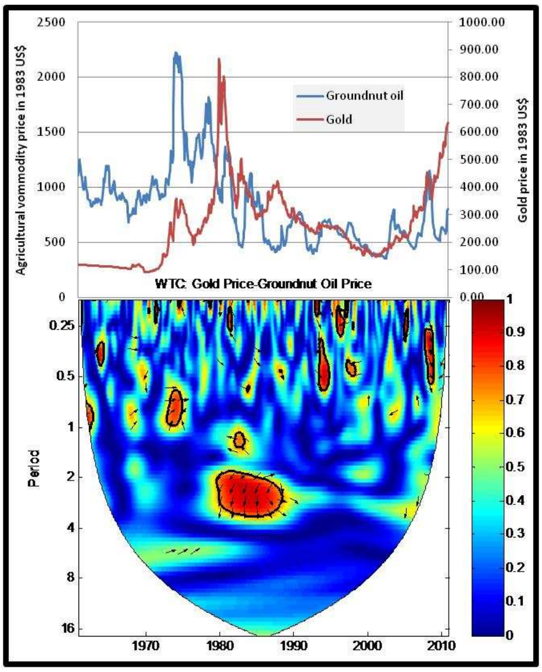
A.3.1 Wavelet Coherence – Gold Price

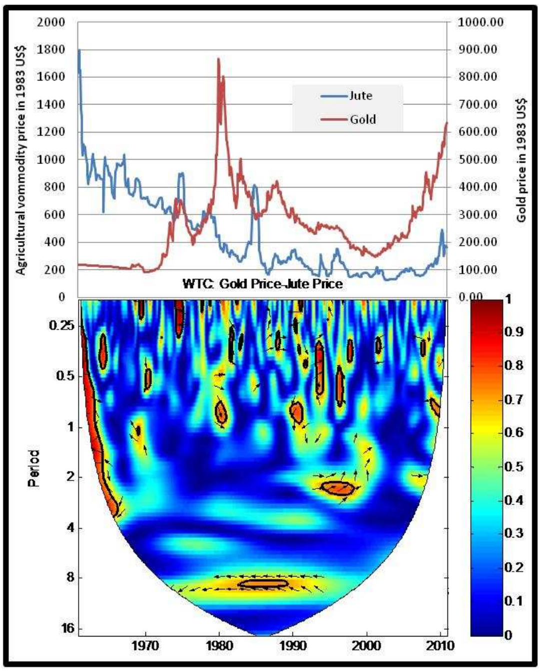


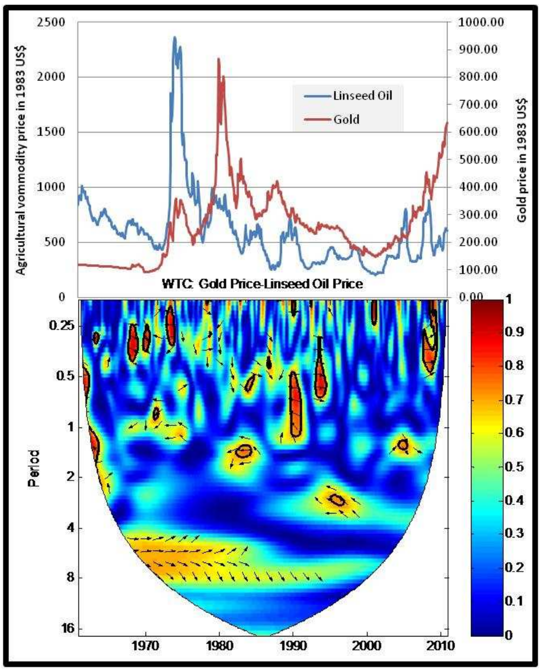


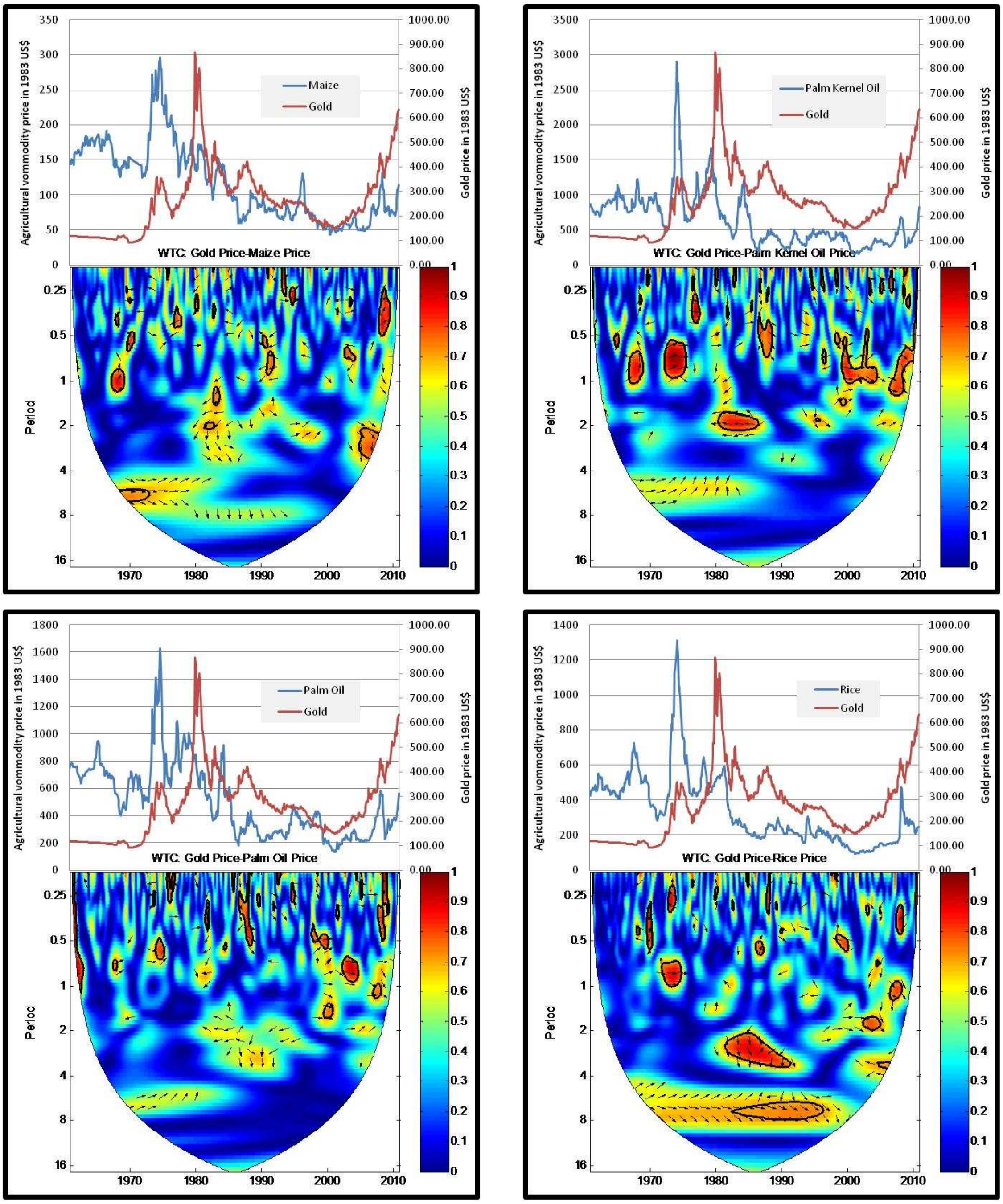
Coffee Arabica
Gold
WTC: Gold Price-Coffee Arabica Price
Coffee Robusta
Gold
WTC: Gold Price-Coffee Robusta Price
Copra
Gold
WTC: Gold Price-Copra Price
Cotton
Gold
WTC: Gold Price-Cotton Price
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Period

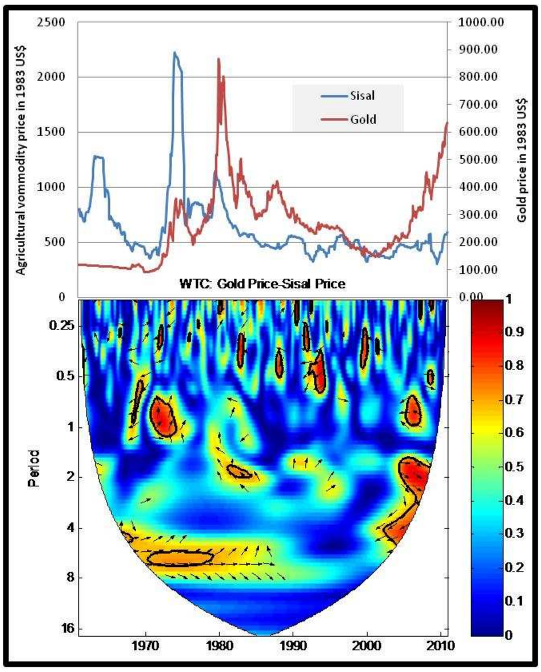

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Cottonseed Oil
Gold
WTC: Gold Price-Cottonseed Oil Price
Period


Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Groundnut oil
Gold
WTC: Gold Price-Groundnut Oil Price
Period

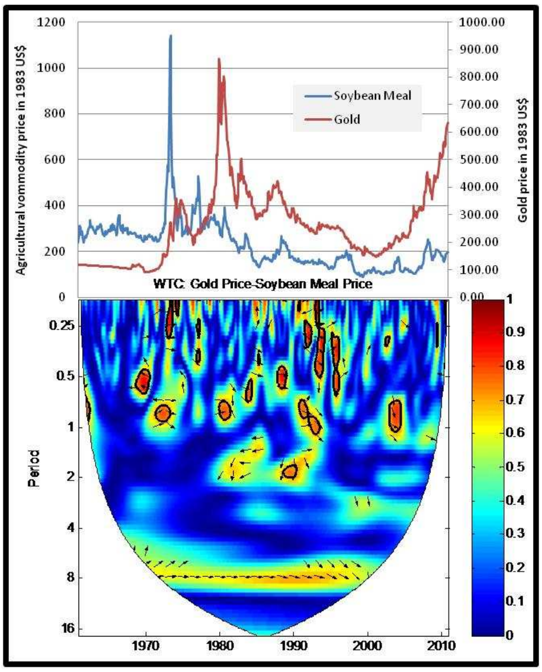

Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Jute
Gold
WTC: Gold Price-Jute Price
Period


Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Linseed Oil
Gold
WTC: Gold Price-Linseed Oil Price
Period

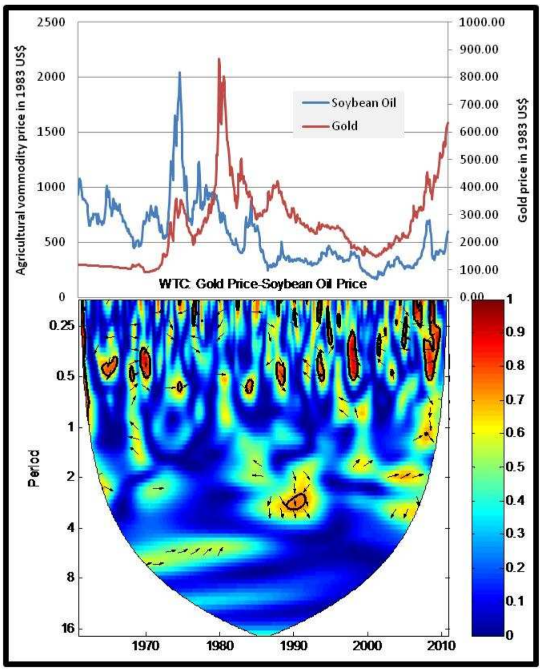

Maize
Gold
WTC: Gold Price-Maize Price
Palm Kernel Oil
Gold
WTC: Gold Price-Palm Kernel Oil Price
Palm Oil
Gold
WTC: Gold Price-Palm Oil Price
Rice
Gold
WTC: Gold Price-Rice Price
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
Period



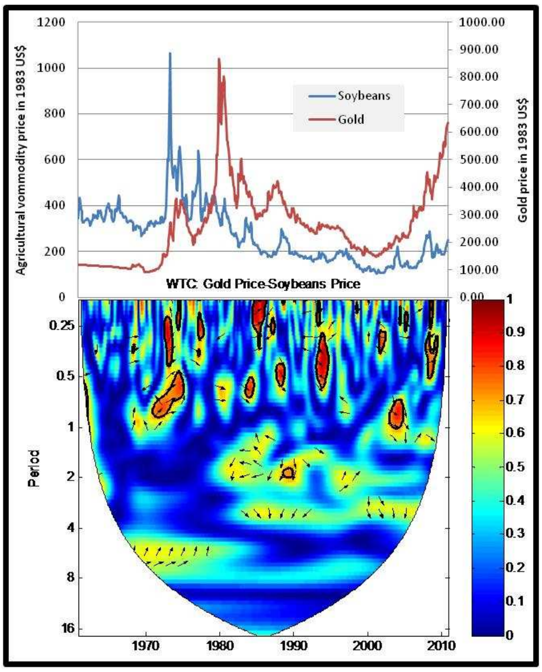
Sisal
Gold
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
WTC: Gold Price-Sisal Price
Period



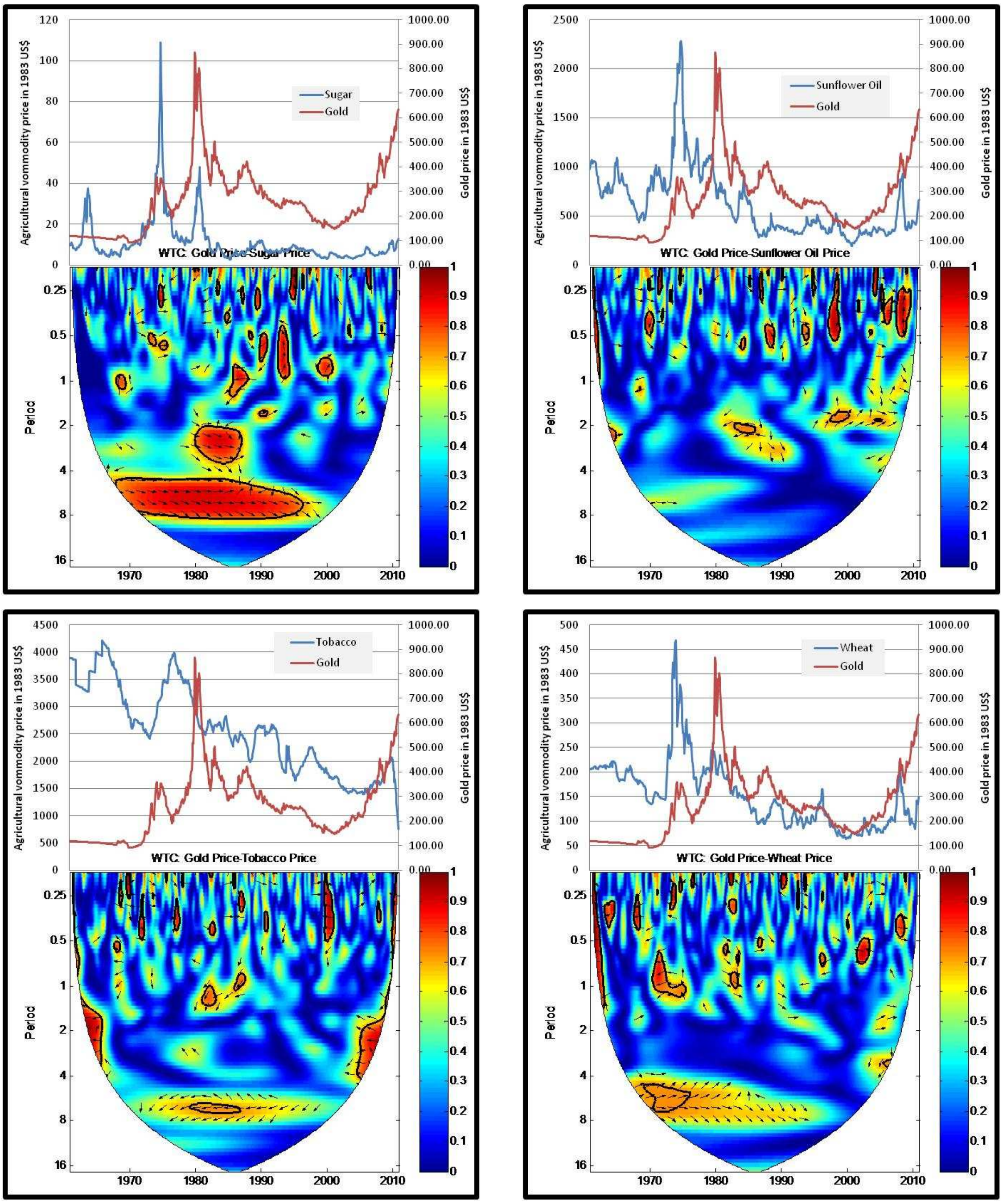
Soybean Meal
Gold
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
WTC: Gold Price-Soybean Meal Price
Period



Soybean Oil
Gold
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
WTC: Gold Price-Soybean Oil Price
Period

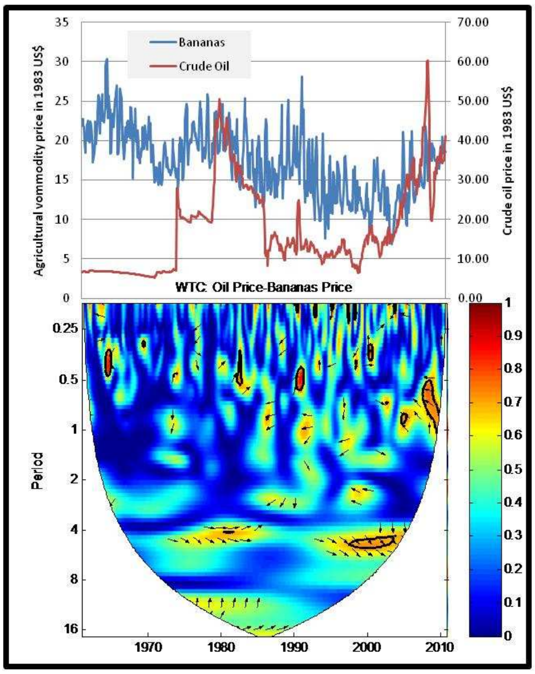


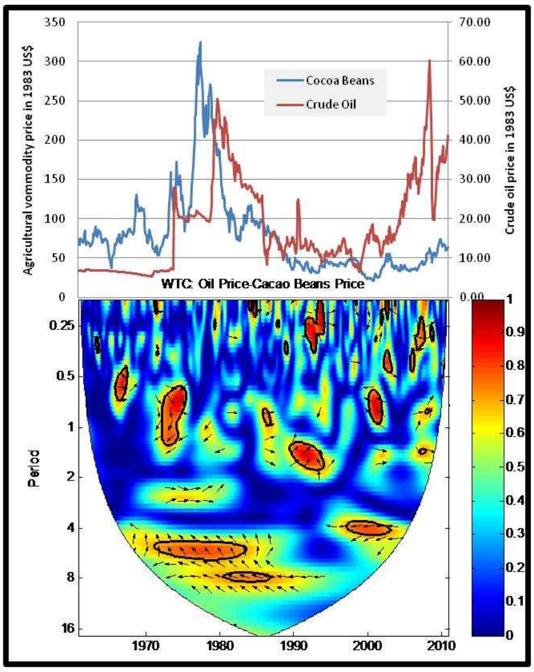
Soybeans
Gold
Agricultural vommodity price in 1983 US$
Gold price in 1983 US$
WTC: Gold Price-Soybeans Price
Period

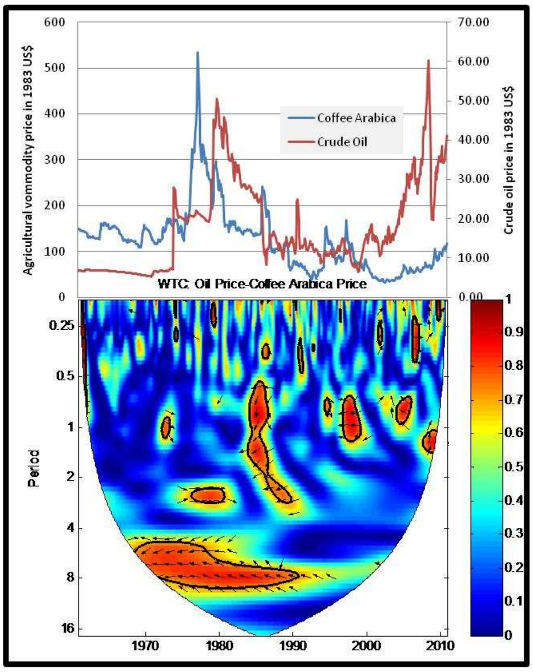


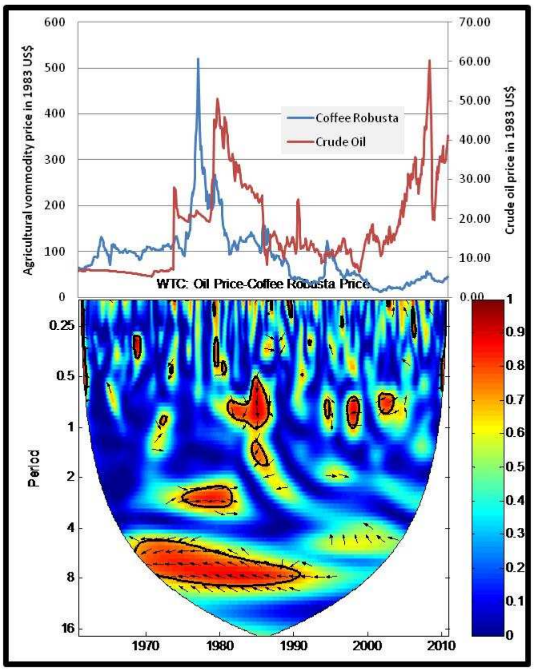
Figure_Apx 5 WTC Results – Gold Price

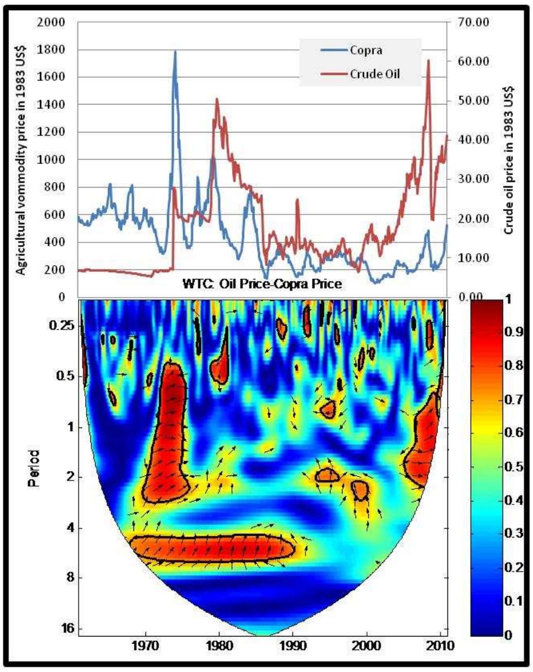
A.3.2 Wavelet Coherence – Crude oil Price

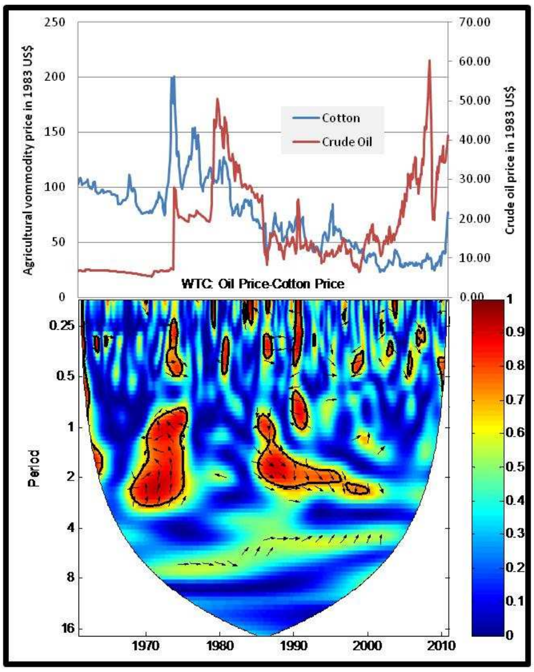


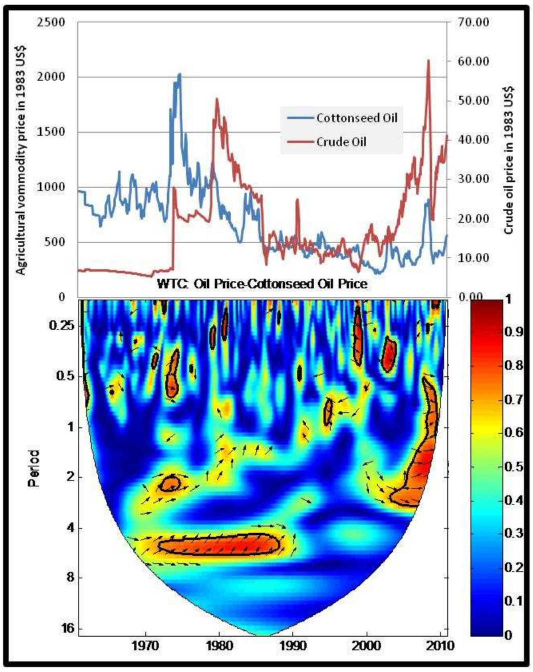


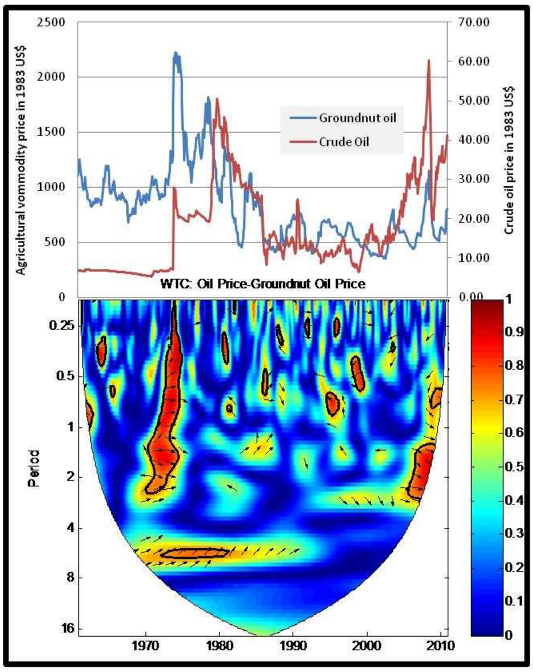


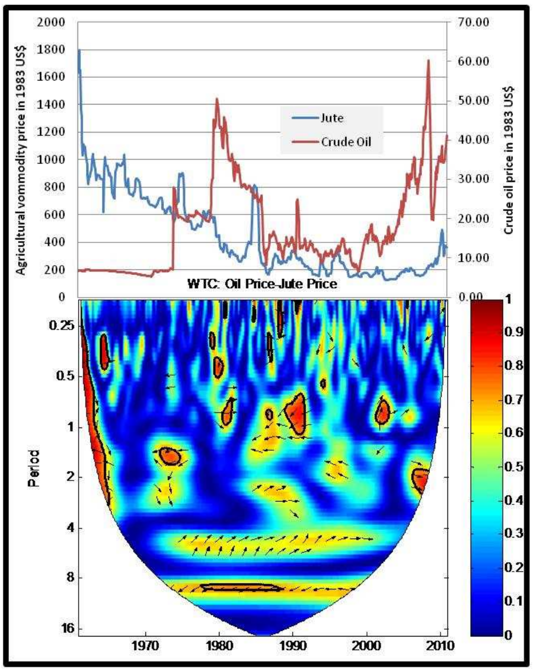


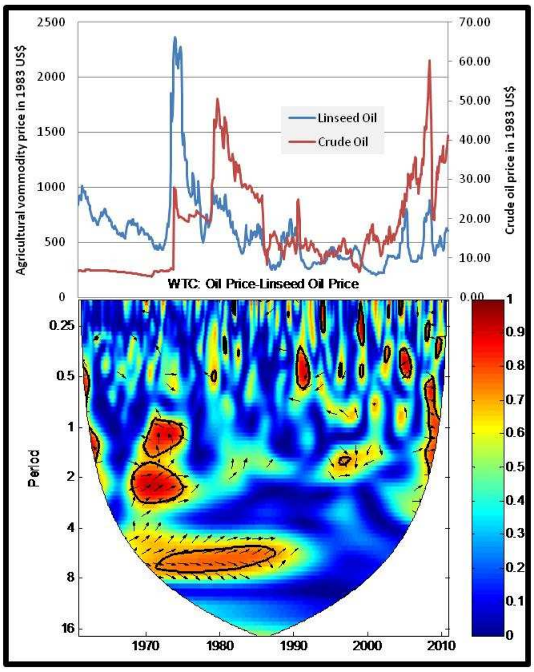

Copra
Crude Oil
WTC: Oil Price-Copra Price
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Period

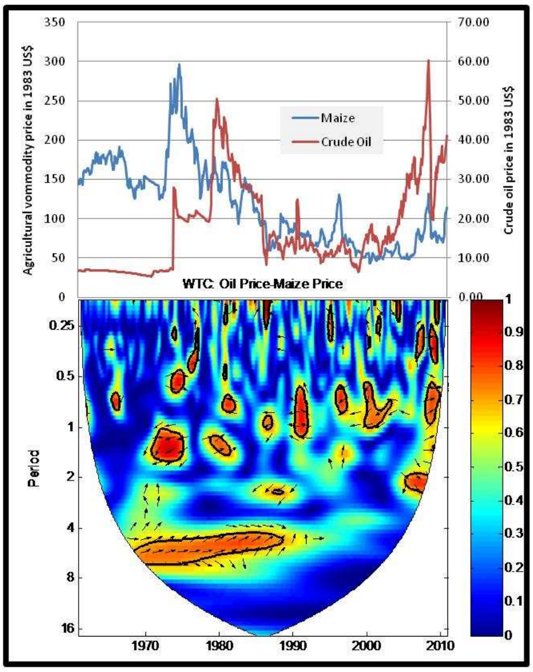

Cotton
Crude Oil
WTC: Oil Price-Cotton Price
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Period

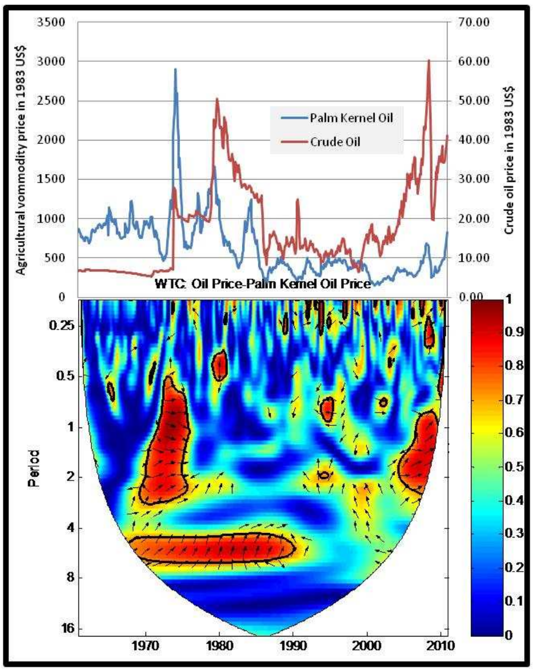

Cottonseed Oil
Crude Oil
WTC: Oil Price-Cottonseed Oil Price
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Period

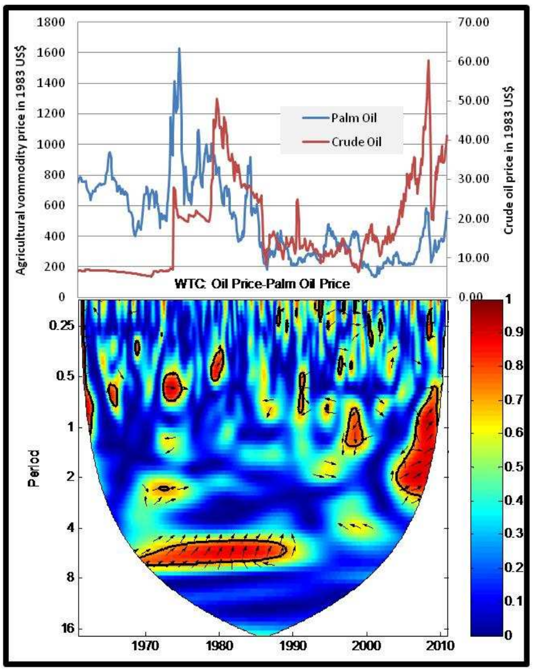

Groundnut oil
Crude Oil
WTC: Oil Price-Groundnut Oil Price
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Period

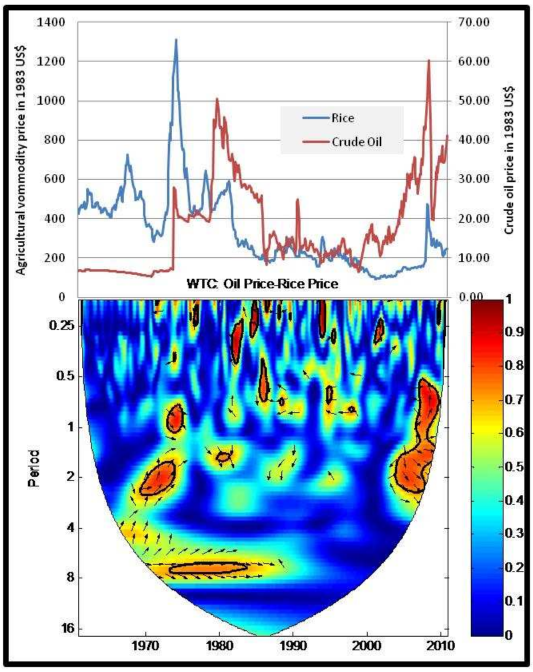

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Jute
Crude Oil
WTC: Oil Price-Jute Price
Period

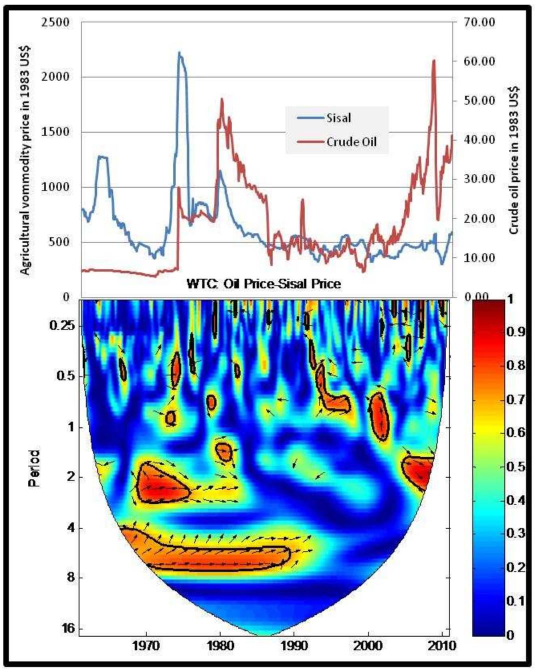

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Linseed Oil
Crude Oil
WTC: Oil Price-Linseed Oil Price
Period

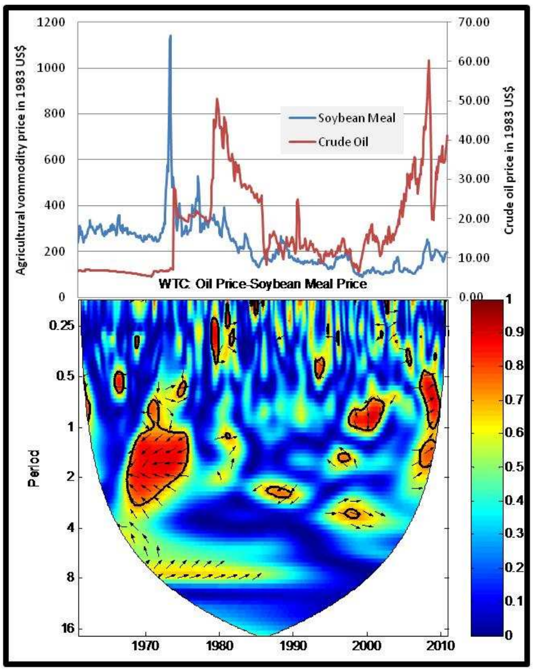

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Maize
Crude Oil
WTC: Oil Price-Maize Price
Period

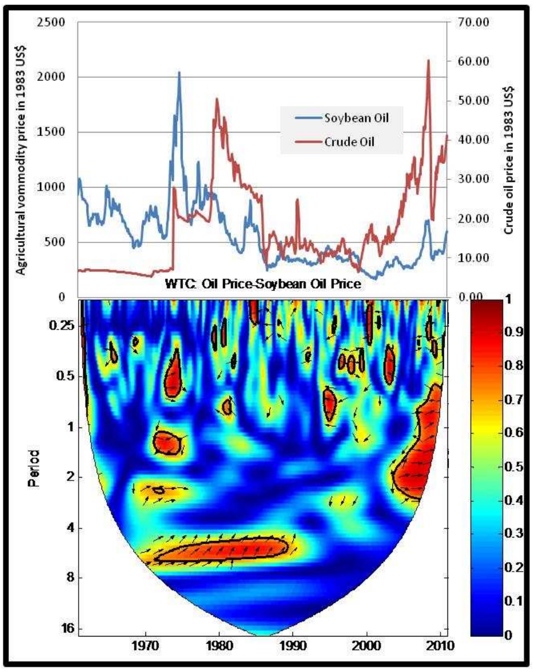

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Palm Kernel Oil
Crude Oil
WTC: Oil Price-Palm Kernel Oil Price
Period

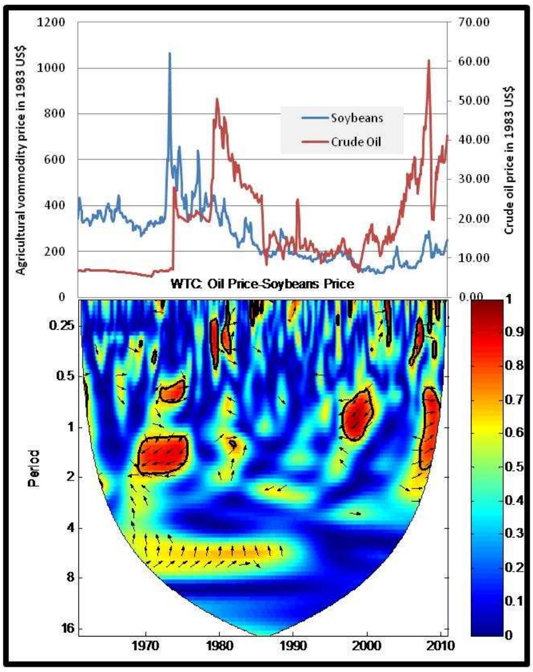

Palm Oil
Crude Oil
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
WTC: Oil Price-Palm Oil Price
Period

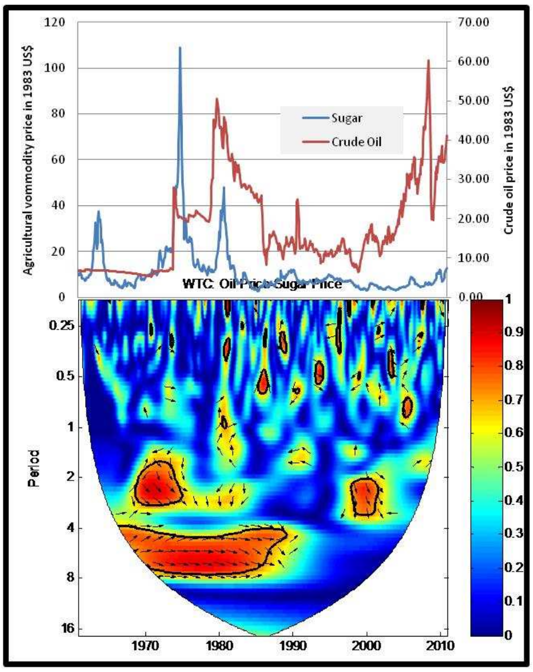

Rice
Crude Oil
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
WTC: Oil Price-Rice Price
Period

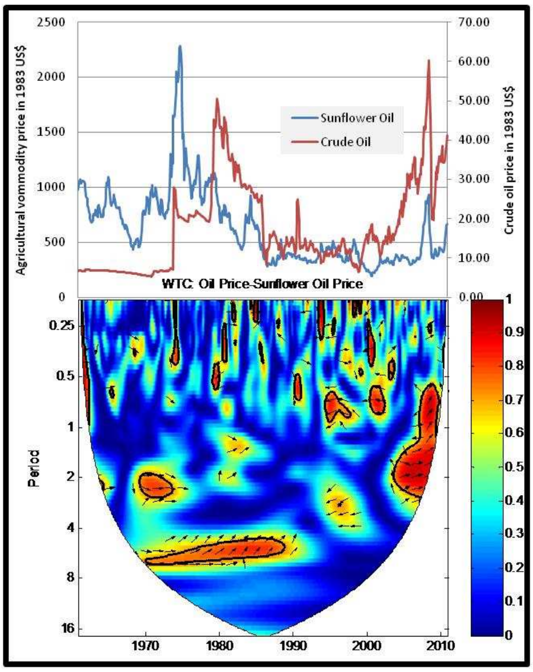

Sisal
Crude Oil
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
WTC: Oil Price-Sisal Price
Period

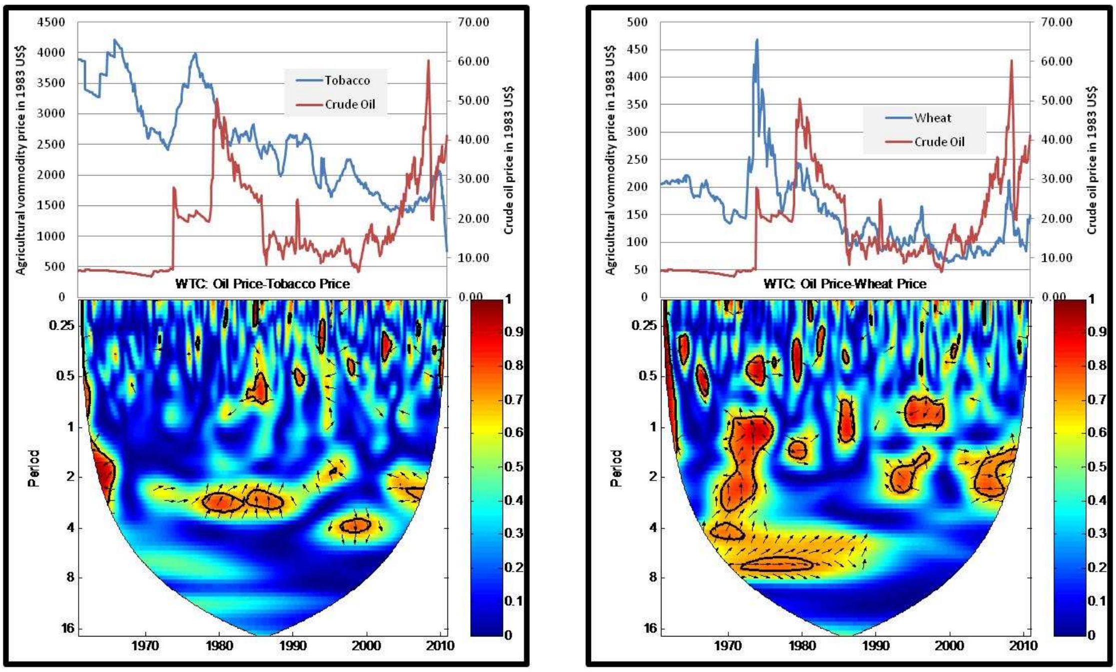

Soybean Meal
Crude Oil
Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
WTC: Oil Price-Soybean Meal Price
Period


Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Soybean Oil
Crude Oil
WTC: Oil Price-Soybean Oil Price
Period
1970 1980 1990 2000 2010


Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Soybeans
Crude Oil
WTC: Oil Price-Soybeans Price
Period
1970 1980 1990 2000 2010

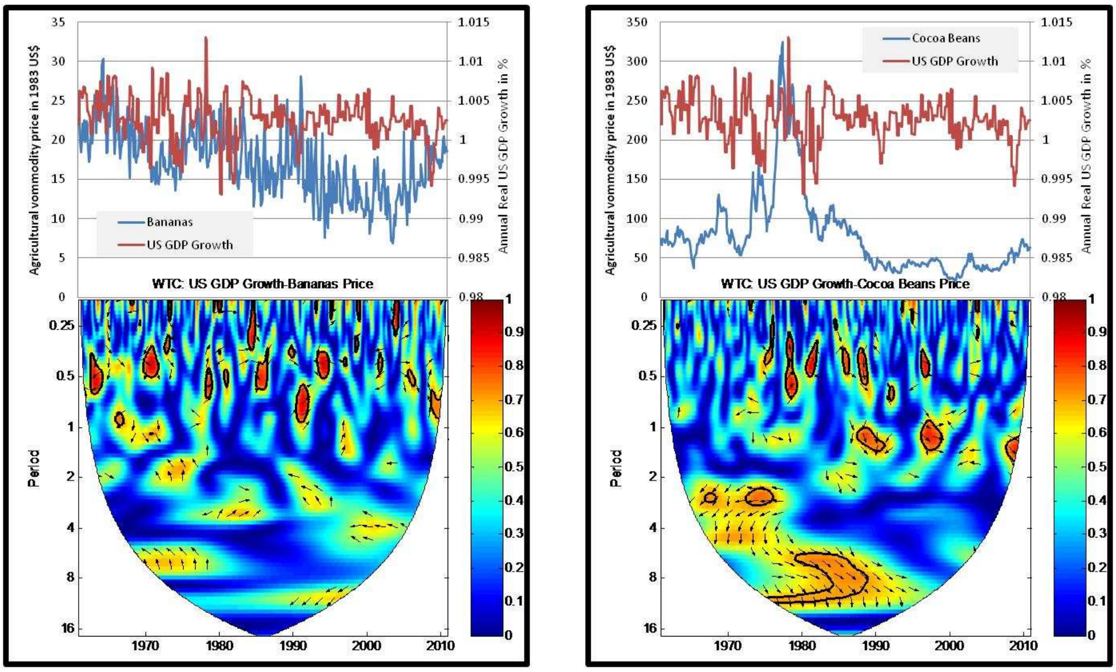

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Sugar
Crude Oil
WTC: Oil Price-Sugar Price
Period
1970 1980 1990 2000 2010

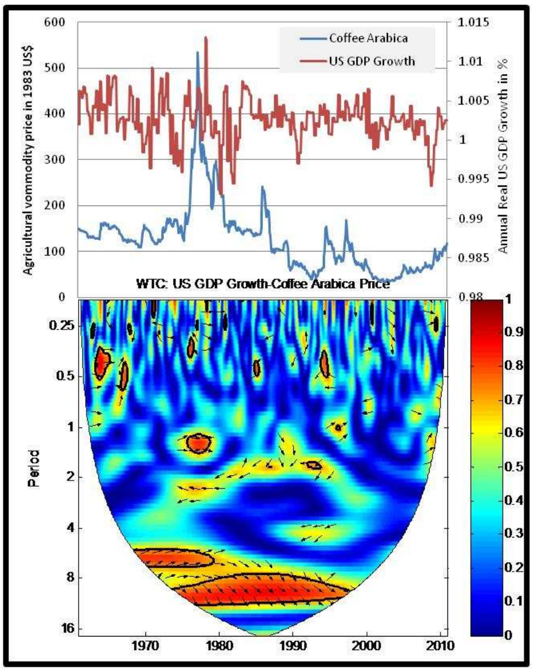

Agricultural vommodity price in 1983 US$
Crude oil price in 1983 US$
Sunflower Oil
Crude Oil
WTC: Oil Price-Sunflower Oil Price
Period
1970 1980 1990 2000 2010

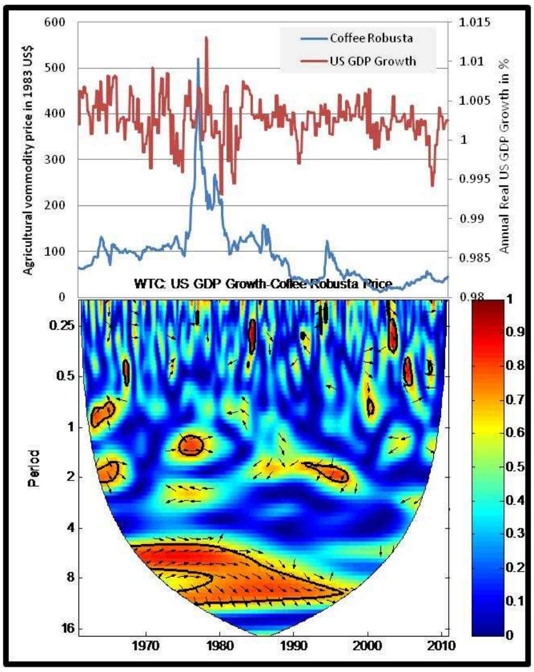


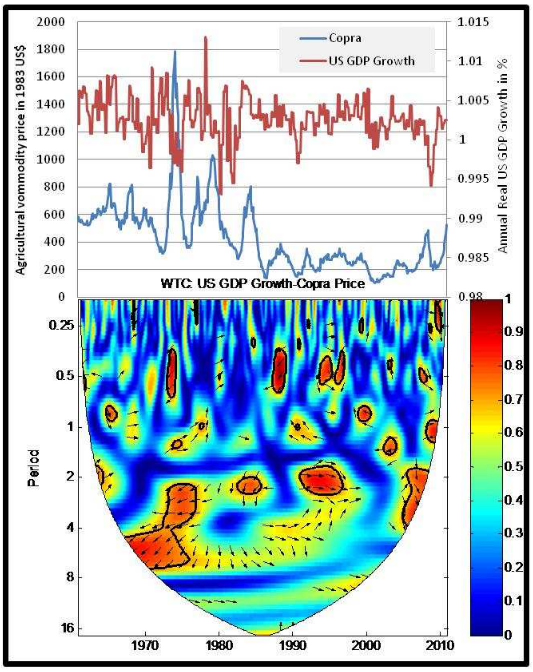
Figure_Apx 6 WTC Results – Crude oil Price

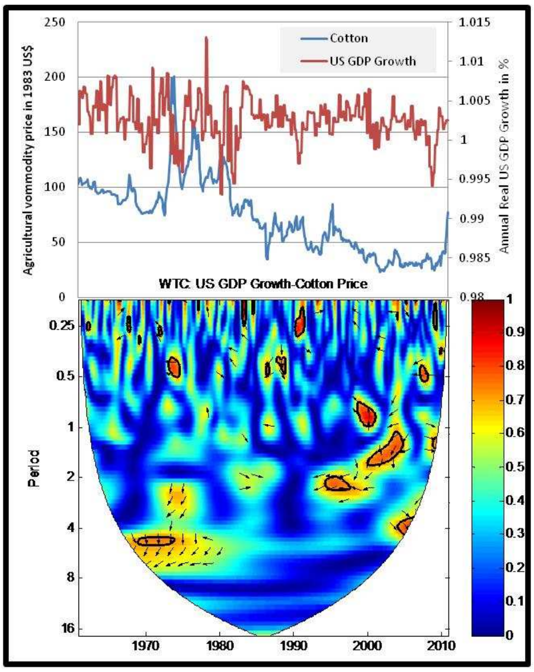
Wavelet Coherence – US GDP Growth

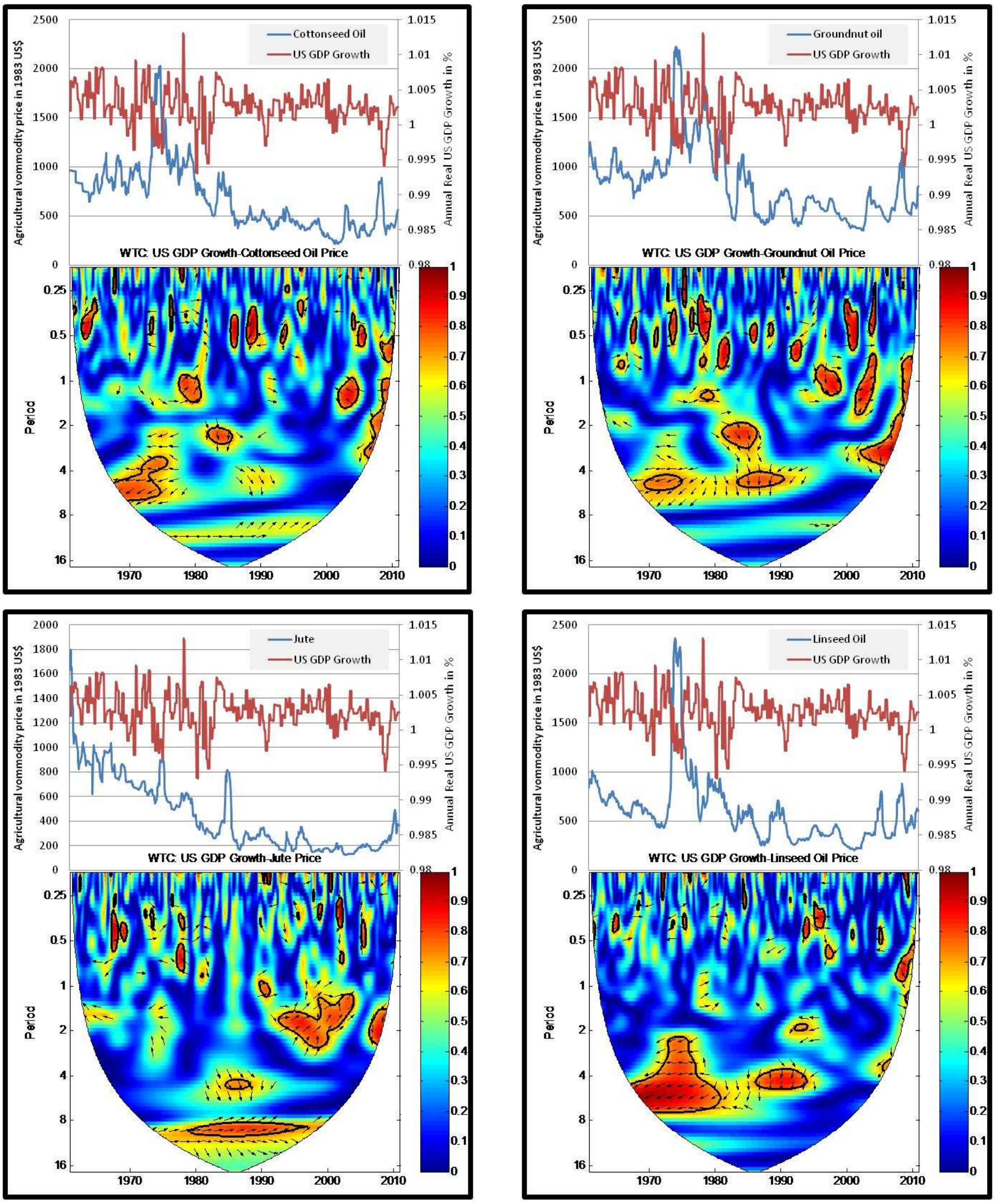



Coffee Arabica
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Coffee Arabica Price
Period
1970
1980
1990
2000
2010

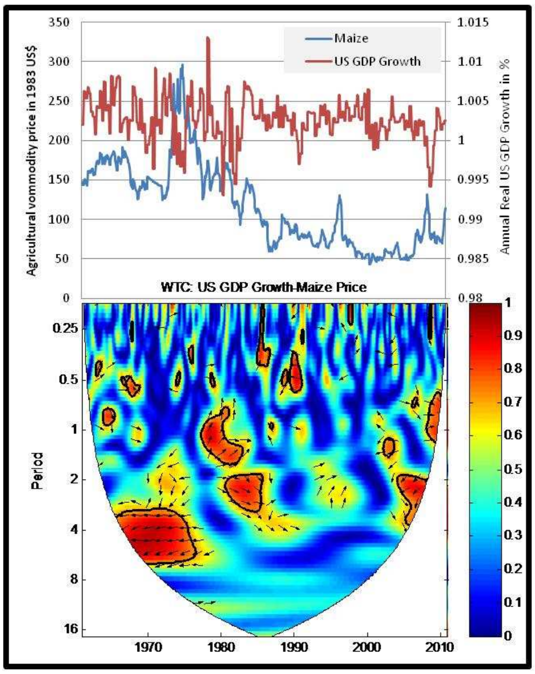

Coffee Robusta
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Coffee Robusta Price
Period
1970
1980
1990
2000
2010

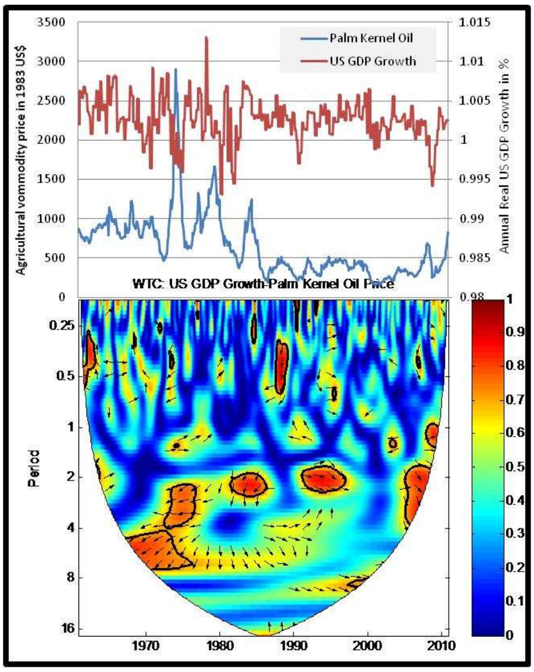

Copra
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Copra Price
Period
1970
1980
1990
2000
2010

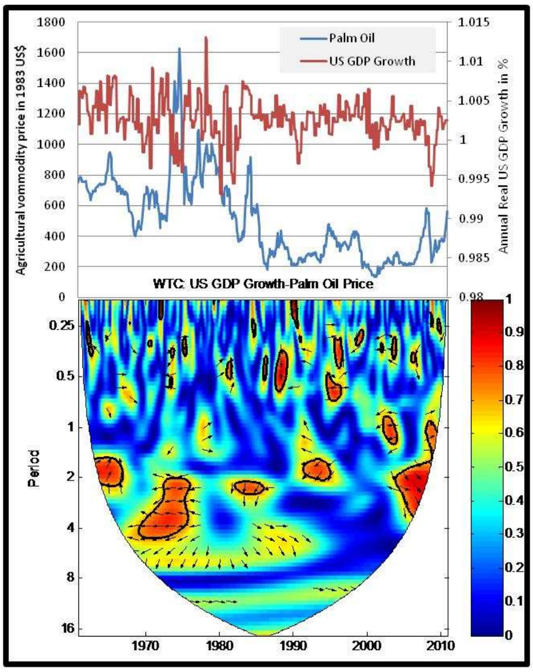

Cotton
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Cotton Price
Period
1970
1980
1990
2000
2010

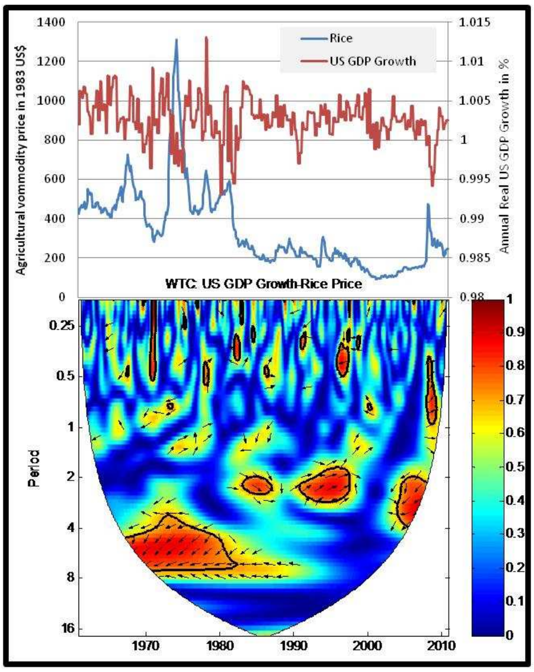


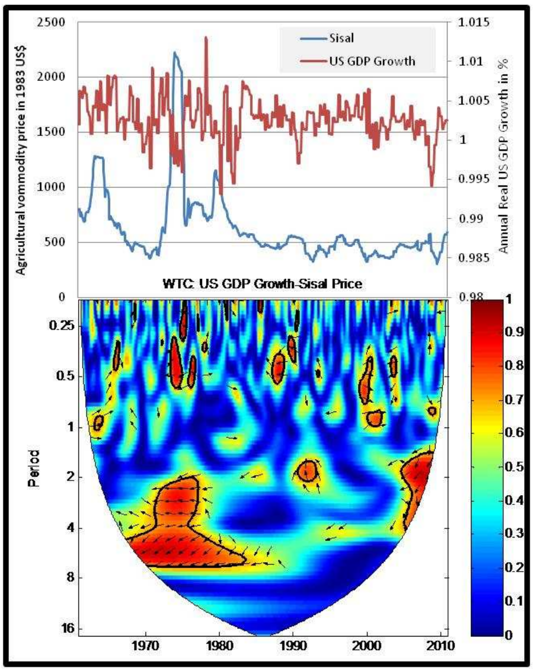
Cottonseed Oil
US GDP Growth
WTC: US GDP Growth-Cottonseed Oil Price
Groundnut oil
US GDP Growth
WTC: US GDP Growth-Groundnut Oil Price
Jute
US GDP Growth
WTC: US GDP Growth-Jute Price
Linseed Oil
US GDP Growth
WTC: US GDP Growth-Linseed Oil Price
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
Period

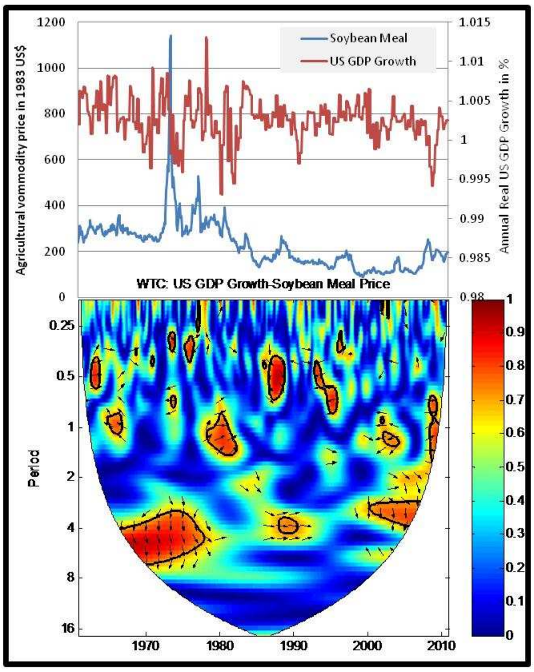

Maize
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Maize Price
Period

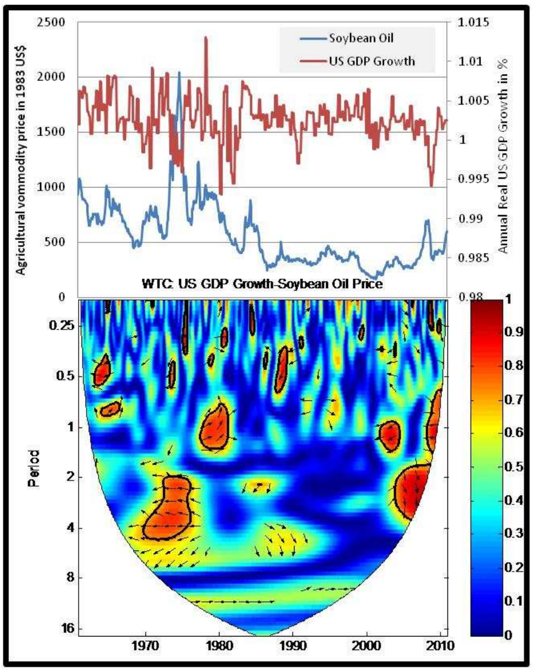

Palm Kernel Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Palm Kernel Oil Price
Period

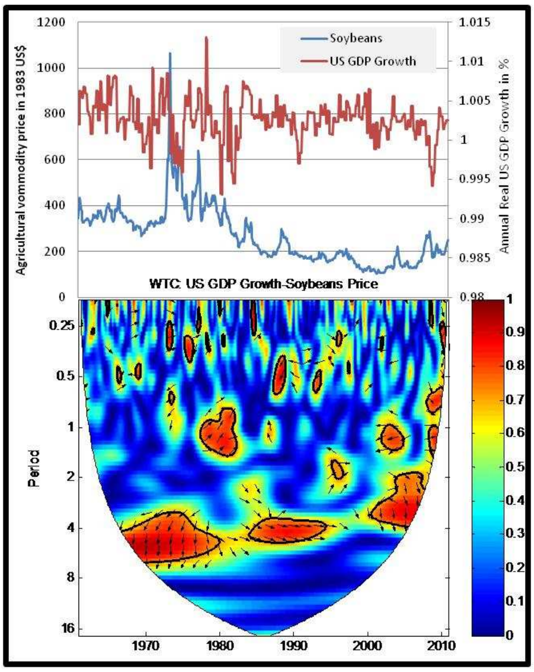

Palm Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Palm Oil Price
Period

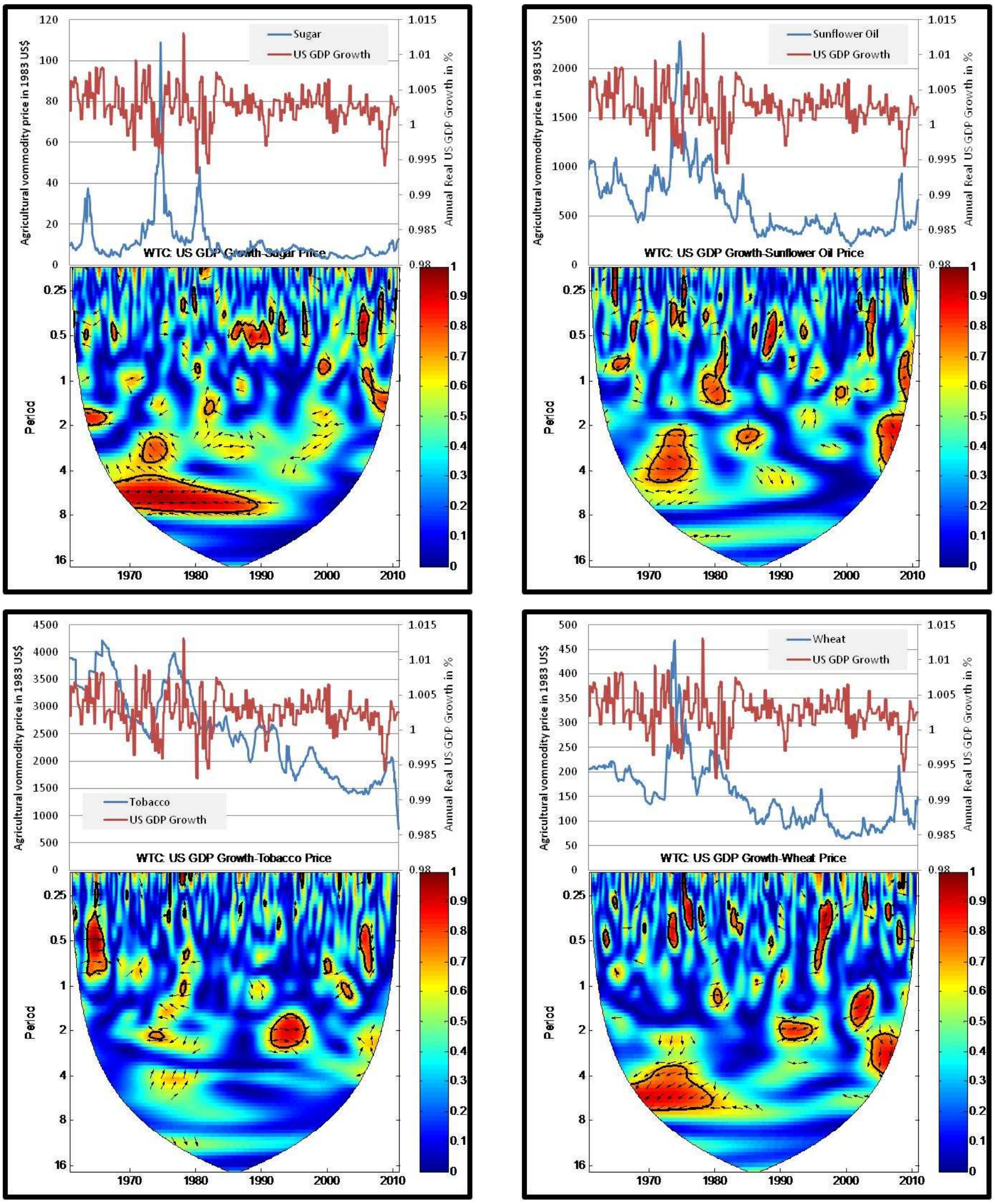

Rice
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Rice Price
Period


Sisal
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Sisal Price
Period


Soybean Meal
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Soybean Meal Price
Period


Soybean Oil
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Soybean Oil Price
Period


Soybeans
US GDP Growth
Agricultural vommodity price in 1983 US$
Annual Real US GDP Growth in %
WTC: US GDP Growth-Soybeans Price
Period



Figure_Apx 7 WTC Results – US GDP Growth

Appendix B Main Wavelet Analysis Results (Text)

B.1 Continuous Wavelet Transform

Bananas: Significant cycles (1 year frequency cycle between 1977 and 1980; 1982 and 1986; 1988 and 1994; 2005 and 2006) and insignificants cycles (1 year frequency cycle between 1962 and 2009; 6 year frequency cycle between 1968 and 1995; 10 year frequency cycle between 1975 and 1998).

Cocoa Beans: Significant cycles (many cycles shorter than 2 year frequency between 1972 and 1981; 5 year frequency cycle between 1967 and 1979; 8 year cycle between 1971 and 1989) and insignificant cycles (4 year frequency cycle between 1968 and 2002; 8 year frequency cycle between 1971 and 1994).

Coffee Arabica: Significant cycles (many shorter than 2 year frequency cycles between 1975 and 1980; 3 year frequency cycle between 1974 and 1997; 4 year frequency cycle between 1971 and 1981; 8 year frequency cycle between 1973 and 1990) and insignificant cycles (8 year frequency cycle between 1973 and 1998).

Coffee Robusta: Significant cycles (many shorter than 2 year frequency cycles between 1975 and 1981; 3 year frequency cycle between 1972 and 1982; 8 year frequency cycle between 1971 and 1990) and insignificant cycles (8 year frequency cycle between 1971 and 1998).

Copra: Significant cycles (1 ½ year frequency cycle between 1972 and 1975; 4 year frequency cycle between 1968 and 1984; 6 year frequency cycle between 1967 and 1988) and insignificant cycles (10 year frequency cycle between 1976 and 1995). There is a break in the significant 4 year frequency cycle between 1978 and 1983.

Cotton: Significant cycles (2 year frequency cycle between 1985 and 1988; 4 year frequency cycle between 1969 and 1984; 6 year frequency cycle between

1970 and 1972) and insignificant cycles (8 year frequency cycle between 1970 and 1999).

Cottonseed Oil: Significant cycles (many less than 4 year frequency cycles between 1973 and 1978; 3x less than 1 year frequency cycles between 1983 and 1985; 1 year frequency cycle between 2002 and 2003; 3 year frequency cycle between 1968 and 1978; 6 year frequency cycle between 1971 and 1983) and insignificant cycles (3 year frequency cycle between 1968 and 1981; 5 year frequency cycle between 2000 and 2004; 6 year frequency cycle between 1971 and 1988).

Groundnut Oil: Significant cycles (many less than 4 year frequency cycles between 1972 and 1985; 6 year frequency cycle between 1968 and 1991) and insignificant cycles (6 year frequency cycle between 1968 and 1995).

Jute: Significant cycles (3 year frequency cycle between 1983 and 1987) and insignificant cycles (3 year frequency cycle between 1964 and 1988; 6 year frequency cycle between 1968 and 1996; 13 year frequency cycle between 1976 and 1994).

Linseed Oil: Significant cycles (many less than 4 year frequency cycles between 1971 and 1979; ½ year frequency cycle in 2005; 1 ½ year frequency cycle between 2005 and 2009; 2 ½ year frequency cycle between 2004 and 2008; 4 year frequency cycle between 1967 and 1990) and insignificant cycles (4 year frequency cycle between 1967 and 2004; 8 year frequency cycle between 1971 and 2001).

Maize: Significant cycles (1 ½ year frequency cycle between 1973 and 1983; 2006 and 2008; 2 year frequency cycle between 1994 and 1997; 3 year frequency cycle between 1979 and 1984; 4 year frequency cycle between 1967 and 1975; 5 year frequency cycle between 1969 and 1986) and insignificant cycles (7 year frequency cycle between 1986 and 2000; 10 year frequency cycle between 1977 and 1994). There is a break in the significant 1 ½ year frequency cycle in 1975 and 1976.

Palm Kernel Oil: Significant cycles (many less than 4 year frequency cycles between 1971 and 1980; 1 year frequency cycle between 1967 and 1969; 1983 and 1984; 3 year frequency cycle between 1967 and 1985; 6 year frequency cycle between 1968 and 1987) and insignificant cycles (10 year frequency cycle between 1976 and 1997).

Palm Oil: Significant cycles (many less than 4 year frequency cycles between 1972 and 1981; 5 year frequency cycle between 1967 and 1988) and insignificant cycles (4 year frequency cycle between 1967 and 1991; 1996 and 2005; 11 year frequency cycle between 1976 and 1995).

Rice: Significant cycles (many less than 4 year frequency cycles between 1968 and 1984; 1 ½ year frequency cycle between 1993 and 1994; 2007 and 2008; 8 year frequency cycle between 1969 and 1986) and insignificant cycles (8 year frequency cycle between 1969 and 1991).

Sisal: Significant cycles (many less than 4 year frequency cycles between 1972 and 1982; 1 year frequency cycle in 1963; more than 4 year frequency cycles between 1968 and 1984) and insignificant cycles (2 year frequency cycle between 1992 and 2001; 6 year frequency cycle between 1968 and 1992; 8 year frequency cycle between 1968 and 2002).

Soybean Meal: Significant cycles (many less than 4 year frequency cycles between 1971 and 1979; 4 year frequency cycle between 1971 and 1977) and insignificant cycles (2 ½ year frequency cycle between 1981 and 1989; 4 year frequency cycle between 1968 and 2007; 8 year frequency cycle between 1970 and 1996).

Soybean Oil: Significant cycles (many less than 4 year frequency cycles between 1973 and 1979; 2/3 year frequency cycle between 1983 and 1984; 1 ½ year frequency cycle between 2007 and 2008; 2 year frequency cycle between 1963 and 1965; 5 year frequency cycle between 1967 and 1987) and insignificant cycles (5 year frequency cycle between 1967 and 1991; 10 year frequency cycle between 1973 and 1996).

Soybeans: Significant cycles (many less than 4 year frequency cycles between 1971 and 1980; 2/3 year frequency cycle in 1983; 4 year frequency cycle between 1971 and 1977) and insignificant cycles (1 ½ year frequency cycle between 1964 and 1966; 5 ½ year frequency cycle between 1968 and 1992; 8 year frequency cycle between 1971 and 2001).

Sugar: Significant cycles (many less than 4 year frequency cycles between 1971 and 1984; 6 year frequency cycle between 1968 and 1974) and insignificant cycles (1/3 year frequency cycle between 1980 and 1981; 2/3 year frequency cycle in 1963; 6 year frequency cycle between 1968 and 1994).

Sunflower Oil: Significant cycles (many less than 4 year frequency cycles between 1973 and 1980; 1/3 year frequency cycle in 1984 and 2008; 2/3 year frequency cycle in 1984; 3 year frequency cycle between 2006 and 2008; 5 year frequency cycle between 1966 and 1986) and insignificant cycles (5 year frequency cycle between 1966 and 1992; 10 year frequency cycle between 1974 and 1997).

Tobacco: Significant cycles (¼ year frequency cycle in 1994; 2 ½ year frequency cycle between 1987 and 1994; 11 year frequency cycle between 1976 and 1982) and insignificant cycles (2 ½ year frequency cycle between 1970 and 1996; 7 year frequency cycle between 1971 and 2002; 11 year frequency cycle between 1971 and 1996).

Wheat: Significant cycles (many less than 4 year frequency cycles between 1970 and 1978; ¼ year frequency cycle in 2008; ½ year frequency cycle in 2008; 1 year frequency cycle between 1979 and 1982; 1 ½ year frequency cycle between 2006 and 2009; 8 year frequency cycle between 1968 and 1983) and insignificant cycles (4 year frequency cycle between 1970 and 1999; 7 year frequency cycle between 1967 and 2005, from the mid 90s shortening to 6 year frequency; 11 year frequency cycle between 1975 and 1996).

B.2 Cross Wavelet Transform

Bananas: US GDP Growth (1 year frequency cycle in the end of 70s and the beginning of 80s, in phase, US GDP Growth leaded), CPP (6x 1 year frequency cycle during 70s and 80s), Gold price (8 year frequency cycle in 70s – mid 90s, anti phase, Bananas leaded).

Cocoa Beans: US GDP Growth (High frequency cycle in 70s and 80s, in phase, Cocoa Beans leaded), CPP (High frequency cycle in 70s - mid 80s, anti phase, CPP leaded), Gold price (High frequency cycle in 70s and 80s, anti phase, Gold price leaded).

Coffee Arabica: US GDP Growth (High frequency cycle in 70s and 80s, in phase, Coffee Arabica leaded), CPP (High frequency cycle in 70s - mid 80s, anti phase), Gold price (High frequency cycle in 70s and 80s, anti phase, Gold price leaded).

Coffee Robusta: US GDP Growth (High frequency cycle in 70s and 80s, in phase, Coffee Robusta leaded), CPP (High frequency cycle in 70s - mid 80s, anti phase), Gold price (High frequency cycle in 70s and 80s, anti phase, Gold price leaded).

Copra: US GDP Growth (High frequency cycle in 70s and 80s, anti phase, Copra leaded), CPP (High frequency cycle in 70s and 80s, in phase, CPP leaded), Gold price (High frequency in 70s - mid 80s, in phase, Gold price leaded).

Cotton: US GDP Growth (High frequency cycle in 70s, anti phase, Cotton leaded), CPP (3 year frequency cycle in 70s, in phase, CPP leaded), Gold price (7 year frequency cycle in 70s, in phase).

Cottonseed Oil: US GDP Growth (High frequency cycle in 70s, anti phase, Cottonseed Oil leaded), CPP (High frequency in 70s and 80s, in phase, CPP leaded), Gold price (High frequency cycle in 70s and 80s, in phase).

Groundnut Oil: US GDP Growth (High frequency cycle in 70s and 80s, anti phase, Groundnut Oil leaded), CPP (High frequency cycle in 70s and 80s, in phase, CPP leaded), Gold price (High frequency cycle in 70s and 80s, in phase, Gold price leaded).

Jute: US GDP Growth (3 year frequency cycle, anti phase), CPP (5 year frequency cycle in 78-86, in phase, CPP leaded), Gold price (5 year frequency cycle in 78-84, Gold price leaded).

Linseed Oil: US GDP Growth (High frequency cycle in 70s and 80s, anti phase, Linseed Oil leaded), CPP (High frequency cycle in 70s - mid 80s, in phase), Gold price (High frequency cycle in 70s and 80s, in phase).

Maize: US GDP Growth (High frequency cycle in mid 60s – mid 80s, anti phase), CPP (High frequency cycle in 70s – mid 80s, in phase), Gold price (High frequency cycle in 70s – mid 80s, in phase).

Palm Kernel Oil: US GDP Growth (High frequency cycle in 70s and 80s, anti phase, Palm Kernel Oil leaded), CPP (5 year frequency cycle in 70s and 80s, in phase, CPP leaded), Gold price (High frequency cycle in 70s and 80s, in phase, Gold price leaded).

Palm Oil: US GDP Growth (High frequency cycle in 70s and 80s, anti phase, Palm Oil leaded), CPP (5 year frequency cycle in 70s – mid 80s, in phase, CPP leaded), Gold price (High frequency cycle in 70s - mid 80s, in phase, Gold price leaded).

Rice: US GDP Growth (High frequency cycle in 70s - mid 80s, anti phase, Rice leaded), CPP (High frequency cycle in 70s, in phase), Gold price (High frequency cycle in 70s and 80s, in phase).

Sisal: US GDP Growth (High frequency cycle in 70s - mid 80s, anti phase, Sisal leaded), CPP (High frequency cycle in 70s - mid 80s, in phase), Gold price (High frequency cycle in 70s and 80s, in phase).

Soybean Meal: US GDP Growth (High frequency cycle in 70s, Soybean Meal leaded), CPP (5 year frequency cycle in 70s, anti phase, CPP leaded), Gold price (High frequency cycle in 70s, in phase, Gold price leaded).

Soybean Oil: US GDP Growth (High frequency cycle in 70s and 80s, anti phase, Soybean Oil leaded), CPP (5 year frequency cycle in 70s and 80s, in phase, CPP leaded), Gold price (High frequency cycle in 70s - mid 80s, in phase, Gold price leaded).

Soybeans: US GDP Growth (High frequency cycle in 70s, Soybeans leaded), CPP (5 year frequency cycle in 70s, anti phase, CPP leaded), Gold price (High frequency cycle in 70s, in phase, Gold price leaded).

Sugar: US GDP Growth (High frequency cycle in 70s - mid 80s, anti phase), CPP (High frequency cycle in 70s - mid 80s, in phase), Gold price (High frequency cycle in 70s and 80s, in phase).

Sunflower Oil: US GDP Growth (High frequency cycle in 70s - mid 80s, anti phase, Sunflower Oil leaded), CPP (5 year frequency cycle in 70s - mid 80s, in phase, CPP leaded), Gold price (5 year frequency cycle in 70s - mid 80s, in phase, Gold price leaded).

Tobacco: US GDP Growth (7 year frequency cycle between 1975 and 1985, in phase, US GDP Growth leaded), CPP (no significant covariance), Gold price (8 year frequency cycle in 70s and 80s, anti phase, Tobacco leaded).

Wheat: US GDP Growth (High frequency cycle in 70s - mid 80s, anti phase, Wheat leaded), CPP (5 year frequency cycle in 70s, in phase, CPP leaded), Gold price (High frequency cycle in 70s and 80s, in phase).

B.3 Wavelet Coherence

Bananas: US GDP Growth (many ½ year frequency cycles), CPP (no significant correlation), Gold price (1980 - 1982, 1 year frequency, anti phase, Bananas leaded; 1981 - 1984, in phase).

Cocoa Beans: US GDP Growth (no significant correlation), CPP (1971 - 1983, 5 year frequency, anti phase, CPP leaded; 1989 - 1993, 1 ½ year frequency, in phase, CPP leaded; 1997 - 2002, 4 year frequency, anti phase), Gold price (1972 - 1975, ¾ year frequency, in phase, Cocoa Beans leaded; 1975 - 1992, 6 year frequency, anti phase, Gold price leaded; 2006 - 2007, 1 year frequency, in phase, Cocoa Beans leaded).

Coffee Arabica: US GDP Growth (70s, 80s and 90s, 12 year frequency, in phase, Coffee Arabica leaded), CPP (70s and 80s, 8 year frequency, anti phase; 1976 - 1980, 3 year frequency, in phase; 1997 - 1999, 1 year frequency, anti phase), Gold price (70s and 80s, 8 year frequency, anti phase, Gold price leaded; 1991 - 1997, 2 year frequency, anti phase, Coffee Arabica leaded).

Coffee Robusta: US GDP Growth (70s, 80s and 90s, 12 year frequency, in phase, Coffee Robusta leaded), CPP (70s and 80s, 7 year frequency, anti phase; 1975 - 1981, 3 year frequency, in phase), Gold price (70s and 80s, 8 year frequency, anti phase, Gold price leaded; 1991 - 1998, 2 year frequency, anti phase, Coffee Robusta leaded).

Copra: US GDP Growth (1970 - 1975, 6 year frequency, anti phase, Copra leaded; 1987 - 1988, ½ year frequency, anti phase, Copra leaded; 1991 - 1996, 2 year frequency, in phase), CPP (70s and 80s, 6 year frequency, CPP leaded; 1970 - 1975, in phase), Gold price (1980 - 1986, 2 year frequency, anti phase; 6x high levels of correlation in different years, 1 year frequency).

Cotton: US GDP Growth (no significant correlation), CPP (1968 - 1975, 1 - 3 year frequency, CPP leaded; 1985 - 1996, 2 year frequency, in phase, Cotton leaded), Gold price (1983 - 1988, 3 year frequency, in phase, Cotton leaded; many high levels of correlation in different years, 1 year frequency).

Cottonseed Oil: US GDP Growth (1968 - 1973, 6 year frequency, anti phase, Cottonseed Oil leaded; 1988 - 1989, ½ year frequency, anti phase, Cottonseed Oil leaded), CPP (70s and 80s, 5 year frequency, in phase, CPP leaded; 2003 - 2009, 3 year frequency, in phase), Gold price (1979 - 1984, 2 year frequency, anti phase, Cottonseed Oil leaded).

Groundnut Oil: US GDP Growth (1968 - 1991, 5 year frequency, anti phase, Groundnut Oil leaded; 1995 - 1999, 1 year frequency, Groundnut Oil leaded), CPP (1970 - 1974, in phase; 70s and 80s, 6 year frequency, in phase, CPP leaded; 2006 - 2009, 3 year frequency, in phase, Groundnut Oil leaded), Gold price (80s, 3 year frequency, anti phase, Groundnut Oil leaded).

Jute: US GDP Growth (80s and 90s, 9 year frequency, in phase; 90s, 2 year frequency, in phase, US GDP Growth leaded), CPP (1974 - 1997, 9 year frequency, anti phase, Jute leaded; 1989 - 1991, 1 year frequency, anti phase, Jute leaded), Gold price (1980 - 1993, 9 year frequency, anti phase; 1994 - 1998, 3 year frequency, in phase, Gold price leaded).

Linseed Oil: US GDP Growth (70s, 6 year frequency, anti phase; 1986 - 1993, 4 year frequency, Linseed Oil leaded), CPP (70s and 80s, 6 year frequency, in phase, CPP leaded; 1968 - 1975, 2 year frequency, in phase, CPP leaded), Gold price (70s - mid 80s, 6 year frequency, in phase; 1990, 1 year frequency, anti phase, Gold price leaded).

Maize: US GDP Growth (1967 – 1975, 6 year frequency, anti phase; 1981 – 1985, 2 year frequency, in phase, Maize leaded; 2004 – 2007, 2 year frequency, anti phase, Maize leaded), CPP (1969 – 1988, 6 year frequency, in phase, CPP leaded; 1971 – 1974, 1 ½ year frequency; anti phase, Maize leaded; 2005 – 2007, 2 year frequency, in phase, Maize leaded), Gold price (1969 – 1973, 6 year frequency, in phase; 2004 – 2007, 3 year frequency, Maize leaded).

Palm Kernel Oil: US GDP Growth (1981 - 1985; 2 year frequency, Palm Kernel Oil leaded; 1988, ½ year frequency, Palm Kernel Oil leaded; 1991 - 1996, 2 year frequency, in phase, Palm Kernel Oil leaded), CPP (70s and 80s, 6 year frequency, in phase, CPP leaded; 1970 - 1975, 1 year frequency, in phase; 2004 - 2009, in phase), Gold price (1972 - 1975, ¾ year frequency, in phase; 1980 - 1986, 2 year frequency, anti phase; 1999 and 2004, 1 year frequency, in phase).

Palm Oil: US GDP Growth (1969 - 1975, 4 year frequency, anti phase; 1991 - 1994, 2 year frequency, anti phase, Palm Oil leaded), CPP (70s and 80s, 6 year frequency, in phase, CPP leaded; 2004 - 2009, in phase), Gold price (no significant correlation, only low frequency locally correlated cycles).

Rice: US GDP Growth (70s and 80s, 6 year frequency, anti phase; 1990 - 1997, 2 year frequency, in phase, US GDP Growth leaded), CPP (1969 - 1973, 2 year frequency, in phase, CPP leaded; 1974 - 1983, 7 year frequency, in phase; 2004 - 2007, 2 year frequency, Rice leaded), Gold price (1969 - 1996, 7 year frequency, in phase, Rice leaded; 1981 - 1991, 3 year frequency, Rice leaded).

Sisal: US GDP Growth (70s - mid 80s, 6 year frequency, anti phase, Sisal leaded), CPP (70s and 80s, 6 year frequency, in phase; 2004 - 2009, 2 year frequency, in phase, Sisal leaded), Gold price (1969 - 1982, 7 year frequency, in phase; 2002 - 2009, 4 year frequency, anti phase, Sisal leaded; 2005 - 2009, 2 year frequency, in phase, Sisal leaded).

Soybean Meal: US GDP Growth (70s, 6 year frequency, Soybean Meal leaded; 1987 - 1988, ½ year frequency, Soybean Meal leaded; 2000 - 2009, 3 year frequency, Soybean Meal leaded), CPP (1968 and 1975, 1 ½ year frequency, anti phase, Soybean Meal leaded; 1997 - 2001, 1 year frequency, Soybean Meal leaded; 2007 - 2008, ¾ year frequency, in phase, CPP leaded), Gold price (1972 - 1999, 8 year frequency, in phase).

Soybean Oil: US GDP Growth (1970 - 1975, 4 year frequency, anti phase; 1977 - 1981, 1 year frequency, in phase, US GDP Growth leaded; 2004 - 2009, 3 year frequency, Soybean Oil leaded), CPP (70s and 80s, 6 year frequency, in phase, CPP leaded; 2004 - 2009, 2 year frequency, in phase), Gold price (1989 - 1991, 3 year frequency, in phase, Soybean Oil leaded).

Soybeans: US GDP Growth (70s, 6 year frequency, Soybeans leaded; 1985 - 1995, 4 year frequency, in phase; 2000 - 2009, 3 year frequency, Soybeans leaded), CPP (1969 and 1975, 1 ½ year frequency, anti phase, Soybeans leaded; 1996 - 2000, 1 year frequency, anti phase, Soybeans leaded), Gold price (no significant correlation, only low frequency locally correlated cycles).

Sugar: US GDP Growth (70s and 80s, 6 year frequency, anti phase), CPP (70s and 80s, 5 year frequency, in phase; 1998 - 2001, 3 year frequency, Sugar leaded), Gold price (70s, 80s and 90s, 7 year frequency, in phase; 1980 - 1986, 3 year frequency, in phase, Sugar leaded).

Sunflower Oil: US GDP Growth (1970 - 1975, 4 year frequency, anti phase), CPP (70s and 80s, 6 year frequency, in phase, CPP leaded; 2004 - 2009, 2 year frequency, in phase), Gold price (no significant correlation, only low frequency locally correlated cycles).

Tobacco: US GDP Growth (1991 - 1997, 2 year frequency, in phase), CPP (1978 - 1988, 3 year frequency, CPP leaded; 1996 - 2000, 4 year frequency, Tobacco leaded), Gold price (1976 - 1991, 6 year frequency, anti phase; 2000, anti phase; 2005 - 2009, 3 year frequency, anti phase).

Wheat: US GDP Growth (70s, 6 year frequency, anti phase, Wheat leaded), CPP (70s - mid 80s, 8 year frequency, in phase; 1994 - 1998, 1 year frequency, anti phase, Wheat leaded), Gold price (1968 - 1982, 6 year frequency, in phase, Gold price leaded; 2001 - 2002, ¾ year frequency, anti phase).

Appendix C Commodity Specification

Table_Apx 1 Detailed Specifications of Investigated Commodities

	Commodity	Specification
Agricultural Raw Materials	Copra	Copra, in bulk, Philippines/Indonesia, CIF N.W. European ports
	Cotton	Cotton, U.S. Memphis/Eastern, Midd.1-3/32", CFR Far Eastern quotations
	Jute	Jute, Bangladesh, BWD, FOB Mongla
	Sisal	Sisal, Tanzania/Kenya, n° 3 & UG, CIF main European ports
Cereals	Cocoa Beans	Cocoa beans, average daily prices New York/London
	Coffee Arabica	Coffee, Colombian mild Arabicas, ex-dock New York
	Coffee Robusta	Coffee, Robustas, ex-dock New York
Beverages	Maize	Maize (corn), U.S. No. 2 Yellow, FOB Gulf of Mexico, U.S. price
	Rice	Rice, Thailand, white milled, 5% broken, nominal price quotes, FOB Bangkok
	Wheat	Wheat, United States, n° 2 Hard Red Winter (ordinary), FOB Gulf
Soybean Products	Soybean Meal	Soybean meal, in bulk, 44/45% protein, Hamburg FOB ex-mill
	Soybean Oil	Soybean oil, in bulk, The Netherlands, FOB ex-mill
	Soybeans	Soybeans, in bulk, United States, n° 2 yellow, CIF Rotterdam
Vegetable Oils	Cottonseed Oil	Cottonseed oil, in bulk, United States, PBSY, FOB Gulf
	Groundnut oil	Groundnut oil, in bulk, any origin, CIF Rotterdam
	Linseed Oil	Linseed oil, in bulk, any origin, ex-tank, Rotterdam
	Palm Kernel Oil	Palm kernel oil, in bulk, Malaysia, CIF Rotterdam
	Palm Oil	Palm oil, in bulk, Malaysia/Indonesia, 5% ffa, CIF N.W. European ports
	Sunflower Oil	Sunflower oil, in bulk, European Union, FOB N.W. European ports
Other	Bananas	Bananas, Central America and Ecuador, U.S. importer's price, FOB U.S. ports
	Sugar	Sugar, average of I.S.A. daily prices, FOB Caribbean ports
	Tobacco	Tobacco, unmanufactured, U.S. import unit value

Appendix D Matlab Source Codes

D.1 Continuous Wavelet Transform

```
function varargout=wt(d,varargin)
%% Continous Wavelet Transform
% Creates a figure of wavelet power in units of
% normalized variance.
%
% USAGE: [wave,period,scale,coi,sig95]=wt(d[,params])
%
% d: a time series
% wave: the wavelet transform of d
% period: a vector of "Fourier" periods associated with wave
% scale: a vector of wavelet scales associated with wave
% coi: the cone of influence
%
% Settings: Pad: pad the time series with zeros?
% .         Dj: Octaves per scale (default: '1/12')
% .         S0: Minimum scale
% .         J1: Total number of scales
% .         Mother: Mother wavelet (default 'morlet')
% .         MaxScale: An easier way of specifying J1
% .         MakeFigure: Make a figure or simply return the output.
% .         BlackandWhite: Create black and white figures
% .         AR1: the ar1 coefficient of the series
% .              (default='auto' using a naive ar1 estimator. See ar1nv.m)
%
% Settings can also be specified using abbreviations. e.g. ms=MaxScale.
% For detailed help on some parameters type help wavelet.
%
%
% Example:
%      wt([0:200;sin(0:200)],'dj',1/20,'bw','maxscale',32)
%
% (C) Aslak Grinsted 2002-2004
%
% http://www.pol.ac.uk/home/research/waveletcoherence/


% -------------------------------------------------------------------------
%   Copyright (C) 2002-2004, Aslak Grinsted
%   This software may be used, copied, or redistributed as long as it is not
%   sold and this copyright notice is reproduced on each copy made.  This
%   routine is provided as is without any express or implied warranties
%   whatsoever.


% ------validate and reformat timeseries.
[d,dt]=formatts(d);


n=size(d,1);
sigma2=var(d(:,2));


%----------default arguments for the wavelet transform-----------
Args=struct('Pad',1,...      % pad the time series with zeroes (recommended)
            'Dj',1/12, ...    % this will do 12 sub-octaves per octave
            'S0',2*dt,...    % this says start at a scale of 2 years
            'J1',[],...
            'Mother','Morlet', ...
            'MaxScale',[],...   %a more simple way to specify J1
            'MakeFigure',(nargout==0),...
            'BlackandWhite',0,...
            'AR1','auto');
Args=parseArgs(varargin,Args,{'BlackandWhite'});
if isempty(Args.J1)
    if isempty(Args.MaxScale)
        Args.MaxScale=(n*.17)*2*dt; %automaxscale
    end
    Args.J1=round(log2(Args.MaxScale/Args.S0)/Args.Dj);
end


if strcmpi(Args.AR1,'auto')
    Args.AR1=ar1nv(d(:,2));
    if any(isnan(Args.AR1))
        error('Automatic AR1 estimation failed. Specify it manually (use arcov or arburg).')
    end
end
```

```
%----------------:::::::::---------- Analyze: ---------:::::::::::::-----------------

[wave,period,scale,coi] = wavelet(d(:,2),dt,Args.Pad,Args.Dj,Args.S0,Args.J1,Args.Mother);

t=d(:,1);
power = (abs(wave)).^2 ;        % compute wavelet power spectrum
signif = wave_signif(1.0,dt,scale,0,Args.AR1,-1,-1,Args.Mother);
sig95 = (signif')*(ones(1,n));  % expand signif --> (J+1)x(N) array
sig95 = power ./ (sigma2*sig95);
Yticks = 2.^(fix(log2(min(period))):fix(log2(max(period))));

if Args.MakeFigure

    if Args.BlackandWhite
        levels = [0.25,0.5,1,2,4,8,16] ;

        [cout,H]=safecontourf(t,log2(period),log2(abs(power/sigma2)),log2(levels));%,log2(levels));
%*** or use 'contourfill'
        cout(1,:)=2.^cout(1,:);

        HCB=colorbarf(cout,H);
        barylbls=rats([0 levels 0]');
        barylbls([1 end],:)=' ';
        barylbls(:,all(barylbls==' ',1))=[];
        set(HCB,'yticklabel',barylbls);
        cmap=(1:-.01:.5)'*.9;
        cmap(:,2:3)=cmap(:,[1 1]);
        %cmap(:,1:2)=cmap(:,1:2)*.8;
        colormap(cmap);
        set(gca,'YLim',log2([min(period),max(period)]), ...
            'YDir','reverse', ...
            'YTick',log2(Yticks(:)), ...
            'YTickLabel',num2str(Yticks'), ...
            'layer','top')
        %xlabel('Time')
        ylabel('Period')
        hold on

        [c,h] = contour(t,log2(period),sig95,[1 1],'k'); %#ok
        set(h,'linewidth',3)
        plot(t,log2(coi),'k','linewidth',3)
        %hcoi=fill([t([1 1:end end])],log2([period(end) coi period(end)]),'r')
        %set(hcoi,'alphadatamapping','direct','facealpha',.3)

        hold off
    else
        H=imagesc(t,log2(period),log2(abs(power/sigma2)));%#ok,log2(levels));  %*** or use
'contourfill'
        %logpow=log2(abs(power/sigma2));
        %[c,H]=safecontourf(t,log2(period),logpow,[min(logpow(:)):.25:max(logpow(:))]);
        %set(H,'linestyle','none')

        clim=get(gca,'clim'); %center color limits around log2(1)=0
        clim=[-1 1]*max(clim(2),3);
        set(gca,'clim',clim)

        HCB=safecolorbar;
        set(HCB,'ytick',-7:7);
        barylbls=rats(2.^(get(HCB,'ytick')'));
        barylbls([1 end],:)=' ';
        barylbls(:,all(barylbls==' ',1))=[];
        set(HCB,'yticklabel',barylbls);


        set(gca,'YLim',log2([min(period),max(period)]), ...
            'YDir','reverse', ...
            'YTick',log2(Yticks(:)), ...
            'YTickLabel',num2str(Yticks'), ...
            'layer','top')
        %xlabel('Time')
        ylabel('Period')
        hold on
```

```
        [c,h] = contour(t,log2(period),sig95,[1 1],'k'); %#ok
        set(h,'linewidth',2)
        %plot(t,log2(coi),'k','linewidth',3)
        tt=[t([1 1])-dt*.5;t;t([end end])+dt*.5];
        hcoi=fill(tt,log2([period([end 1]) coi period([1 end])]),'w');
        set(hcoi,'alphadatamapping','direct','facealpha',.5)


        hold off
    end
    set(gca,'box','on','layer','top');
end
varargout={wave,period,scale,coi,sig95};
varargout=varargout(1:nargout);



function [cout,H]=safecontourf(varargin) %R14 HACK --- fix.
vv=sscanf(version,'%i.');


if (version('-release')<14)|(vv(1)<7)
    [cout,H]=contourf(varargin{:});
else
    [cout,H]=contourf('v6',varargin{:});
end



function hcb=safecolorbar(varargin)
vv=sscanf(version,'%i.');


if (version('-release')<14)|(vv(1)<7)
    hcb=colorbar(varargin{:});
else
    hcb=colorbar('v6',varargin{:});
end
```

D.2 Cross Wavelet Transform

```
function varargout=xwt(x,y,varargin)
%% Cross wavelet transform
% Creates a figure of cross wavelet power in units of
% normalized variance.
%
% USAGE: [Wxy,period,scale,coi,sig95]=xwt(x,y,[,settings])
%
% x & y: two time series
% Wxy: the cross wavelet transform of x against y
% period: a vector of "Fourier" periods associated with Wxy
% scale: a vector of wavelet scales associated with Wxy
% coi: the cone of influence
%
% Settings: Pad: pad the time series with zeros?
% .         Dj: Octaves per scale (default: '1/12')
% .         S0: Minimum scale
% .         J1: Total number of scales
% .         Mother: Mother wavelet (default 'morlet')
% .         MaxScale: An easier way of specifying J1
% .         MakeFigure: Make a figure or simply return the output.
% .         BlackandWhite: Create black and white figures
% .         AR1: the ar1 coefficients of the series
% .              (default='auto' using a naive ar1 estimator. See ar1nv.m)
% .         ArrowDensity (default: [30 30])
% .         ArrowSize (default: 1)
% .         ArrowHeadSize (default: 1)
%
% Settings can also be specified using abbreviations. e.g. ms=MaxScale.
% For detailed help on some parameters type help wavelet.
%
% Example:
%    t=1:200;
%    xwt(sin(t),sin(t.*cos(t*.01)),'ms',16)
%
% Phase arrows indicate the relative phase relationship between the series
% (pointing right: in-phase; left: anti-phase; down: series1 leading
% series2 by 90°)
%
```

```
% Please acknowledge the use of this software in any publications:
%   "Crosswavelet and wavelet coherence software were provided by
%   A. Grinsted."
%
% (C) Aslak Grinsted 2002-2004
%
% http://www.pol.ac.uk/home/research/waveletcoherence/


% -------------------------------------------------------------------------
%   Copyright (C) 2002-2004, Aslak Grinsted
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%   sold and this copyright notice is reproduced on each copy made.  This
%   routine is provided as is without any express or implied warranties
%   whatsoever.



% ------validate and reformat timeseries.
[x,dt]=formatts(x);
[y,dty]=formatts(y);
if dt~=dty
    error('timestep must be equal between time series')
end
t=(max(x(1,1),y(1,1)):dt:min(x(end,1),y(end,1)))'; %common time period
if length(t)<4
    error('The two time series must overlap.')
end


n=length(t);


%----------default arguments for the wavelet transform-----------
Args=struct('Pad',1,...      % pad the time series with zeroes (recommended)
            'Dj',1/12, ...    % this will do 12 sub-octaves per octave
            'S0',2*dt,...    % this says start at a scale of 2 years
            'J1',[],...
            'Mother','Morlet', ...
            'MaxScale',[],...   %a more simple way to specify J1
            'MakeFigure',(nargout==0),...
            'BlackandWhite',0,...
            'AR1','auto',...
            'ArrowDensity',[30 30],...
            'ArrowSize',1,...
            'ArrowHeadSize',1);
Args=parseArgs(varargin,Args,{'BlackandWhite'});
if isempty(Args.J1)
    if isempty(Args.MaxScale)
        Args.MaxScale=(n*.17)*2*dt; %auto maxscale
    end
    Args.J1=round(log2(Args.MaxScale/Args.S0)/Args.Dj);
end


ad=mean(Args.ArrowDensity);
Args.ArrowSize=Args.ArrowSize*30*.03/ad;
Args.ArrowHeadSize=Args.ArrowHeadSize*Args.ArrowSize*220;



if strcmpi(Args.AR1,'auto')
    Args.AR1=[ar1nv(x(:,2)) ar1nv(y(:,2))];
    if any(isnan(Args.AR1))
        error('Automatic AR1 estimation failed. Specify them manually (use the arcov or arburg
estimators).')
    end
end


%nx=size(x,1);
sigmax=std(x(:,2));


%ny=size(y,1);
sigmay=std(y(:,2));



%-----------:::::::::::::--------- ANALYZE ----------::::::::::::------------


[X,period,scale,coix] = wavelet(x(:,2),dt,Args.Pad,Args.Dj,Args.S0,Args.J1,Args.Mother);%#ok
[Y,period,scale,coiy] = wavelet(y(:,2),dt,Args.Pad,Args.Dj,Args.S0,Args.J1,Args.Mother);
```

```
% truncate X,Y to common time interval (this is first done here so that the coi is minimized)
dte=dt*.01; %to cricumvent round off errors with fractional timesteps
idx=find((x(:,1)>=(t(1)-dte))&(x(:,1)<=(t(end)+dte)));
X=X(:,idx);
coix=coix(idx);

idx=find((y(:,1)>=(t(1)-dte))&(y(:,1)<=(t(end)+dte)));
Y=Y(:,idx);
coiy=coiy(idx);

coi=min(coix,coiy);

% -------- Cross
Wxy=X.*conj(Y);



% sinv=1./(scale');
% sinv=sinv(:,ones(1,size(Wxy,2)));
%
% sWxy=smoothwavelet(sinv.*Wxy,dt,period,dj,scale);
%
Rsq=abs(sWxy).^2./(smoothwavelet(sinv.*(abs(wave1).^2),dt,period,dj,scale).*smoothwavelet(sinv.*(abs(
wave2).^2),dt,period,dj,scale));
% freq = dt ./ period;

%---- Significance levels
%Pk1=fft_theor(freq,lag1_1);
%Pk2=fft_theor(freq,lag1_2);
Pkx=ar1spectrum(Args.AR1(1),period./dt);
Pky=ar1spectrum(Args.AR1(2),period./dt);



V=2;
Zv=3.9999;
signif=sigmax*sigmay*sqrt(Pkx.*Pky)*Zv/V;
sig95 = (signif')*(ones(1,n));  % expand signif --> (J+1)x(N) array
sig95 = abs(Wxy) ./ sig95;
if ~strcmpi(Args.Mother,'morlet')

    sig95(:)=nan;
end

if Args.MakeFigure
    Yticks = 2.^(fix(log2(min(period))):fix(log2(max(period))));
    if Args.BlackandWhite
        levels = [0.25,0.5,1,2,4,8,16];

[cout,H]=safecontourf(t,log2(period),log2(abs(Wxy/(sigmax*sigmay))),log2(levels));%,log2(levels));
%*** or use 'contourf3ill'
        cout(1,:)=2.^cout(1,:);

        HCB=colorbarf(cout,H);
        barylbls=rats([0 levels 0]');
        barylbls([1 end],:)=' ';
        barylbls(:,all(barylbls==' ',1))=[];
        set(HCB,'yticklabel',barylbls);
        cmap=(1:-.01:.5)'*.9;
        cmap(:,2:3)=cmap(:,[1 1]);
        %cmap(:,1:2)=cmap(:,1:2)*.8;
        colormap(cmap);
        set(gca,'YLim',log2([min(period),max(period)]), ...
            'YDir','reverse', ...
            'YTick',log2(Yticks(:)), ...
            'YTickLabel',num2str(Yticks'), ...
            'layer','top')
        %xlabel('Time')
        ylabel('Period')
        hold on

        aWxy=angle(Wxy);

        phs_dt=round(length(t)/Args.ArrowDensity(1)); tidx=max(floor(phs_dt/2),1):phs_dt:length(t);
```

```
        phs_dp=round(length(period)/Args.ArrowDensity(2));
pidx=max(floor(phs_dp/2),1):phs_dp:length(period);
        phaseplot(t(tidx),log2(period(pidx)),aWxy(pidx,tidx),Args.ArrowSize,Args.ArrowHeadSize);


        if strcmpi(Args.Mother,'morlet')
            [c,h] = contour(t,log2(period),sig95,[1 1],'k');%#ok
            set(h,'linewidth',3)
        else
            warning('XWT:sigLevelNotValid','XWT Significance level calculation is only valid for
morlet wavelet.')
            %TODO: alternatively load from same file as wtc (needs to be coded!)
        end


        %tt=[t([1 1])-dt*.5;t;t([end end])+dt*.5];
        %hcoi=patch(tt,log2([period([end 1]) coi period([1 end])]),ones(size(tt))*0,'w');
        %set(hcoi,'alphadatamapping','direct','facealpha',.8)


        plot(t,log2(coi),'k','linewidth',3)
        %hcoi=fill([t([1 1:end end])],log2([period(end) coi period(end)]),'r')
        %set(hcoi,'alphadatamapping','direct','facealpha',.3)
        hold off
    else
        H=imagesc(t,log2(period),log2(abs(Wxy/(sigmax*sigmay))));%#ok
        %logpow=log2(abs(Wxy/(sigmax*sigmay)));
        %[c,H]=safecontourf(t,log2(period),logpow,[min(logpow(:)):.25:max(logpow(:))]);
        %set(H,'linestyle','none')


        clim=get(gca,'clim'); %center color limits around log2(1)=0
        clim=[-1 1]*max(clim(2),3);
        set(gca,'clim',clim)


        HCB=safecolorbar;
        set(HCB,'ytick',-7:7);
        barylbls=rats(2.^(get(HCB,'ytick')'));
        barylbls([1 end],:)=' ';
        barylbls(:,all(barylbls==' ',1))=[];
        set(HCB,'yticklabel',barylbls);


        set(gca,'YLim',log2([min(period),max(period)]), ...
            'YDir','reverse', ...
            'YTick',log2(Yticks(:)), ...
            'YTickLabel',num2str(Yticks'), ...
            'layer','top')
        %xlabel('Time')
        ylabel('Period')
        hold on


        aWxy=angle(Wxy);


        phs_dt=round(length(t)/Args.ArrowDensity(1)); tidx=max(floor(phs_dt/2),1):phs_dt:length(t);
        phs_dp=round(length(period)/Args.ArrowDensity(2));
pidx=max(floor(phs_dp/2),1):phs_dp:length(period);
        phaseplot(t(tidx),log2(period(pidx)),aWxy(pidx,tidx),Args.ArrowSize,Args.ArrowHeadSize);


        if strcmpi(Args.Mother,'morlet')
            [c,h] = contour(t,log2(period),sig95,[1 1],'k');%#ok
            set(h,'linewidth',2)
        else
            warning('XWT:sigLevelNotValid','XWT Significance level calculation is only valid for
morlet wavelet.')
            %TODO: alternatively load from same file as wtc (needs to be coded!)
        end
        tt=[t([1 1])-dt*.5;t;t([end end])+dt*.5];
        hcoi=fill(tt,log2([period([end 1]) coi period([1 end])]),'w');
        set(hcoi,'alphadatamapping','direct','facealpha',.5)
        hold off
    end
end


varargout={Wxy,period,scale,coi,sig95};
varargout=varargout(1:nargout);



function [cout,H]=safecontourf(varargin)
vv=sscanf(version,'%i.');
if (version('-release')<14)|(vv(1)<7)
```

```
    [cout,H]=contourf(varargin{:});
else
    [cout,H]=contourf('v6',varargin{:});
end


function hcb=safecolorbar(varargin)
vv=sscanf(version,'%i.');


if (version('-release')<14)|(vv(1)<7)
    hcb=colorbar(varargin{:});
else
    hcb=colorbar('v6',varargin{:});
end
```

D.3 Wavelet Coherence

```
function varargout=wtc(x,y,varargin)
%% Wavelet coherence
%
% USAGE: [Rsq,period,scale,coi,sig95]=wtc(x,y,[,settings])
%
%
% Settings: Pad: pad the time series with zeros?
% .         Dj: Octaves per scale (default: '1/12')
% .         S0: Minimum scale
% .         J1: Total number of scales
% .         Mother: Mother wavelet (default 'morlet')
% .         MaxScale: An easier way of specifying J1
% .         MakeFigure: Make a figure or simply return the output.
% .         BlackandWhite: Create black and white figures
% .         AR1: the ar1 coefficients of the series
% .              (default='auto' using a naive ar1 estimator. See ar1nv.m)
% .         MonteCarloCount: Number of surrogate data sets in the significance calculation.
(default=300)
% .         ArrowDensity (default: [30 30])
% .         ArrowSize (default: 1)
% .         ArrowHeadSize (default: 1)
%
% Settings can also be specified using abbreviations. e.g. ms=MaxScale.
% For detailed help on some parameters type help wavelet.
%
% Example:
%    t=1:200;
%    wtc(sin(t),sin(t.*cos(t*.01)),'ms',16)
%
% Phase arrows indicate the relative phase relationship between the series
% (pointing right: in-phase; left: anti-phase; down: series1 leading
% series2 by 90°)
%
% Please acknowledge the use of this software in any publications:
%   "Crosswavelet and wavelet coherence software were provided by
%   A. Grinsted."
%
% (C) Aslak Grinsted 2002-2004
%
% http://www.pol.ac.uk/home/research/waveletcoherence/




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%   sold and this copyright notice is reproduced on each copy made.  This
%   routine is provided as is without any express or implied warranties
%   whatsoever.



% ------validate and reformat timeseries.
[x,dt]=formatts(x);
[y,dty]=formatts(y);
if dt~=dty
    error('timestep must be equal between time series')
end
t=(max(x(1,1),y(1,1)):dt:min(x(end,1),y(end,1)))'; %common time period
if length(t)<4
    error('The two time series must overlap.')
```
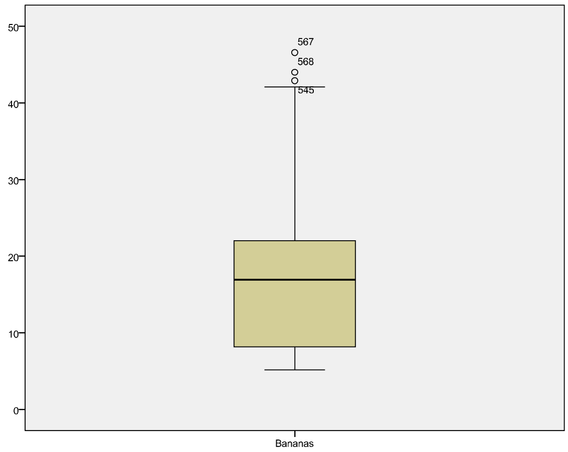

```
end


n=length(t);

%----------default arguments for the wavelet transform-----------
Args=struct('Pad',1,...      % pad the time series with zeroes (recommended)
            'Dj',1/12, ...    % this will do 12 sub-octaves per octave
            'S0',2*dt,...    % this says start at a scale of 2 years
            'J1',[],...
            'Mother','Morlet', ...
            'MaxScale',[],...   %a more simple way to specify J1
            'MakeFigure',(nargout==0),...
            'MonteCarloCount',300,...
            'BlackandWhite',0,...
            'AR1','auto',...
            'ArrowDensity',[30 30],...
            'ArrowSize',1,...
            'ArrowHeadSize',1);
Args=parseArgs(varargin,Args,{'BlackandWhite'});
if isempty(Args.J1)
    if isempty(Args.MaxScale)
        Args.MaxScale=(n*.17)*2*dt; %auto maxscale
    end
    Args.J1=round(log2(Args.MaxScale/Args.S0)/Args.Dj);
end

ad=mean(Args.ArrowDensity);
Args.ArrowSize=Args.ArrowSize*30*.03/ad;
%Args.ArrowHeadSize=Args.ArrowHeadSize*Args.ArrowSize*220;
Args.ArrowHeadSize=Args.ArrowHeadSize*120/ad;

if ~strcmpi(Args.Mother,'morlet')
    warning('WTC:InappropriateSmoothingOperator','Smoothing operator is designed for morlet
wavelet.')
end

if strcmpi(Args.AR1,'auto')
    Args.AR1=[ar1nv(x(:,2)) ar1nv(y(:,2))];
    if any(isnan(Args.AR1))
        error('Automatic AR1 estimation failed. Specify it manually (use arcov or arburg).')
    end
end

nx=size(x,1);
%sigmax=std(x(:,2));

ny=size(y,1);
%sigmay=std(y(:,2));



%-----------:::::::::::::--------- ANALYZE ----------:::::::::::::------------

[X,period,scale,coix] = wavelet(x(:,2),dt,Args.Pad,Args.Dj,Args.S0,Args.J1,Args.Mother);%#ok
[Y,period,scale,coiy] = wavelet(y(:,2),dt,Args.Pad,Args.Dj,Args.S0,Args.J1,Args.Mother);

%Smooth X and Y before truncating!  (minimize coi)
sinv=1./(scale');


sX=smoothwavelet(sinv(:,ones(1,nx)).*(abs(X).^2),dt,period,Args.Dj,scale);
sY=smoothwavelet(sinv(:,ones(1,ny)).*(abs(Y).^2),dt,period,Args.Dj,scale);


% truncate X,Y to common time interval (this is first done here so that the coi is minimized)
dte=dt*.01; %to cricumvent round off errors with fractional timesteps
idx=find((x(:,1)>=(t(1)-dte))&(x(:,1)<=(t(end)+dte)));
X=X(:,idx);
sX=sX(:,idx);
```

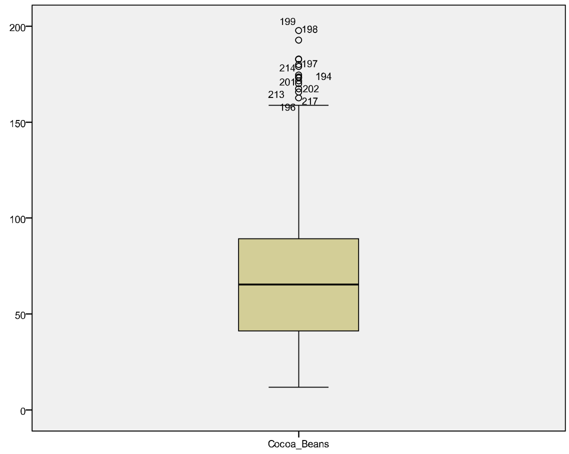
```
coix=coix(idx);

idx=find((y(:,1)>=(t(1))-dte)&(y(:,1)<=(t(end)+dte)));
Y=Y(:,idx);
sY=sY(:,idx);
coiy=coiy(idx);

coi=min(coix,coiy);

% -------- Cross wavelet -------
Wxy=X.*conj(Y);

% ----------------------- Wavelet coherence ---------------------------------
sWxy=smoothwavelet(sinv(:,ones(1,n)).*Wxy,dt,period,Args.Dj,scale);
Rsq=abs(sWxy).^2./(sX.*sY);

if (nargout>0)||(Args.MakeFigure)

wtcsig=wtcsignif(Args.MonteCarloCount,Args.AR1,dt,length(t)*2,Args.Pad,Args.Dj,Args.S0,Args.J1,Args.M
other,.6);
    wtcsig=(wtcsig(:,2))*(ones(1,n));
    wtcsig=Rsq./wtcsig;
end

if Args.MakeFigure



    Yticks = 2.^(fix(log2(min(period))):fix(log2(max(period))));

    if Args.BlackandWhite
        levels = [0 0.5 0.7 0.8 0.9 1];
        [cout,H]=safecontourf(t,log2(period),Rsq,levels);

        colorbarf(cout,H)
        cmap=[0 1;.5 .9;.8 .8;.9 .6;1 .5];
        cmap=interp1(cmap(:,1),cmap(:,2),(0:.1:1)');
        cmap=cmap(:,[1 1 1]);
        colormap(cmap)
        set(gca,'YLim',log2([min(period),max(period)]), ...
            'YDir','reverse', 'layer','top', ...
            'YTick',log2(Yticks(:)), ...
            'YTickLabel',num2str(Yticks'), ...
            'layer','top')
        ylabel('Period')
        hold on

        %phase plot
        aWxy=angle(Wxy);
        aaa=aWxy;
        aaa(Rsq<.5)=NaN;
        %[xx,yy]=meshgrid(t(1:5:end),log2(period));

        phs_dt=round(length(t)/Args.ArrowDensity(1)); tidx=max(floor(phs_dt/2),1):phs_dt:length(t);
        phs_dp=round(length(period)/Args.ArrowDensity(2));
pidx=max(floor(phs_dp/2),1):phs_dp:length(period);
        phaseplot(t(tidx),log2(period(pidx)),aaa(pidx,tidx),Args.ArrowSize,Args.ArrowHeadSize);

        if ~all(isnan(wtcsig))
            [c,h] = contour(t,log2(period),wtcsig,[1 1],'k');%#ok
            set(h,'linewidth',2)
        end
        %suptitle([sTitle ' coherence']);
        plot(t,log2(coi),'k','linewidth',3)
        hold off
    else
        H=imagesc(t,log2(period),Rsq);%#ok
        %[c,H]=safecontourf(t,log2(period),Rsq,[0:.05:1]);
        %set(H,'linestyle','none')

        set(gca,'clim',[0 1])

        HCB=safecolorbar;%#ok
```

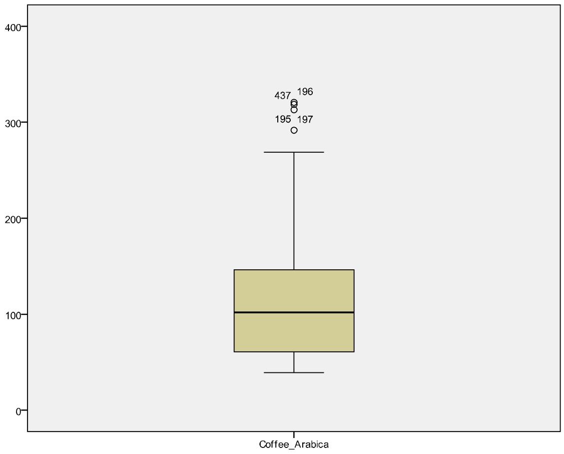
```
        set(gca,'YLim',log2([min(period),max(period)]), ...
            'YDir','reverse', 'layer','top', ...
            'YTick',log2(Yticks(:)), ...
            'YTickLabel',num2str(Yticks'), ...
            'layer','top')
        ylabel('Period')
        hold on


        %phase plot
        aWxy=angle(Wxy);
        aaa=aWxy;
        aaa(Rsq<.5)=NaN; %remove phase indication where Rsq is low
        %[xx,yy]=meshgrid(t(1:5:end),log2(period));


        phs_dt=round(length(t)/Args.ArrowDensity(1)); tidx=max(floor(phs_dt/2),1):phs_dt:length(t);
        phs_dp=round(length(period)/Args.ArrowDensity(2));
pidx=max(floor(phs_dp/2),1):phs_dp:length(period);
        phaseplot(t(tidx),log2(period(pidx)),aaa(pidx,tidx),Args.ArrowSize,Args.ArrowHeadSize);


        if ~all(isnan(wtcsig))
            [c,h] = contour(t,log2(period),wtcsig,[1 1],'k');%#ok
            set(h,'linewidth',2)
        end
        %suptitle([sTitle ' coherence']);
        tt=[t([1 1])-dt*.5;t;t([end end])+dt*.5];
        hcoi=fill(tt,log2([period([end 1]) coi period([1 end])]),'w');
        set(hcoi,'alphadatamapping','direct','facealpha',.5)
        hold off
    end
end


varargout={Rsq,period,scale,coi,wtcsig};
varargout=varargout(1:nargout);


function [cout,H]=safecontourf(varargin)
vv=sscanf(version,'%i.');
if (version('-release')<14)|(vv(1)<7)
    [cout,H]=contourf(varargin{:});
else
    [cout,H]=contourf('v6',varargin{:});
end


function hcb=safecolorbar(varargin)
vv=sscanf(version,'%i.');


if (version('-release')<14)|(vv(1)<7)
    hcb=colorbar(varargin{:});
else
    hcb=colorbar('v6',varargin{:});
end
```

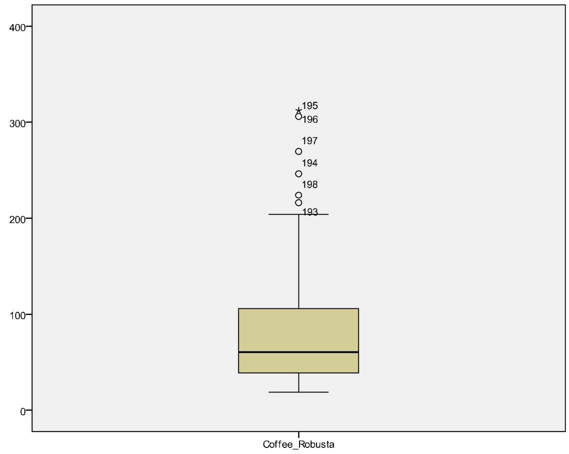
Appendix E Box-Plots

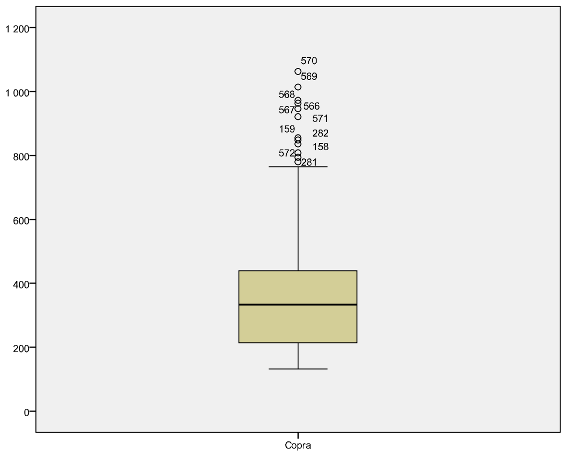
E.1 Commodities

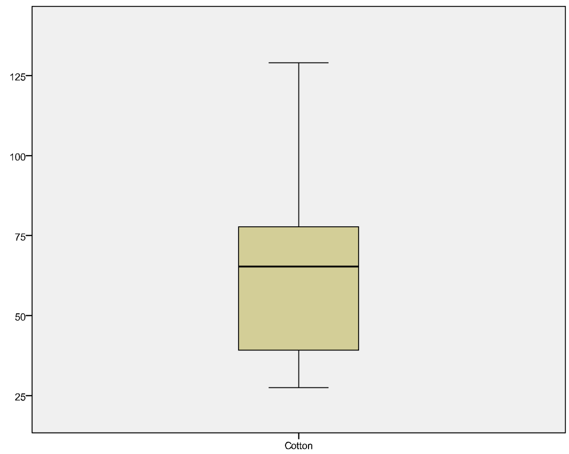


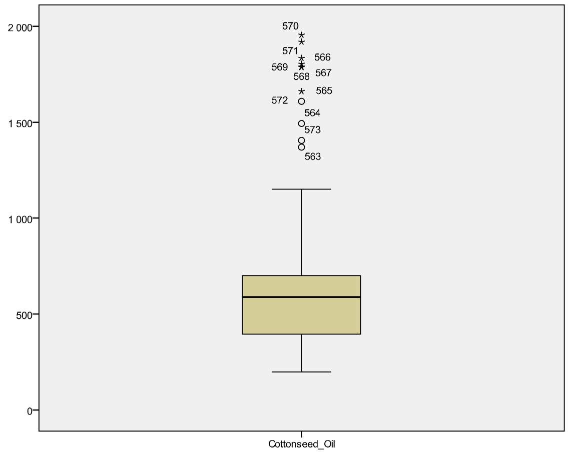


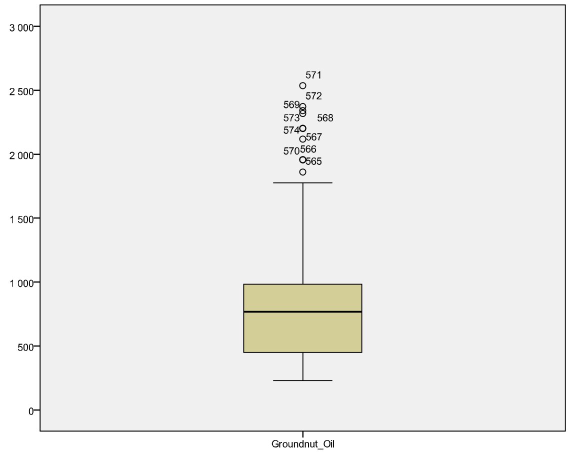


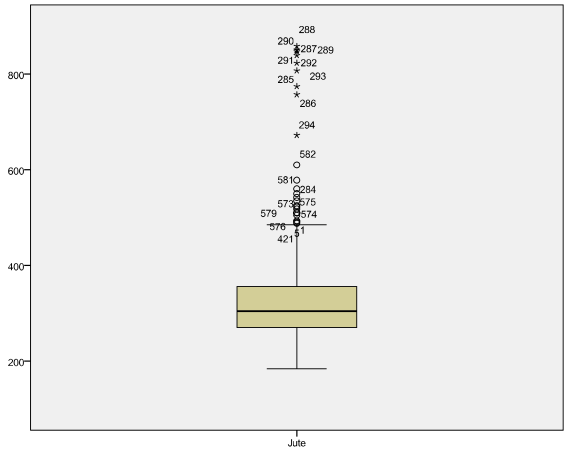


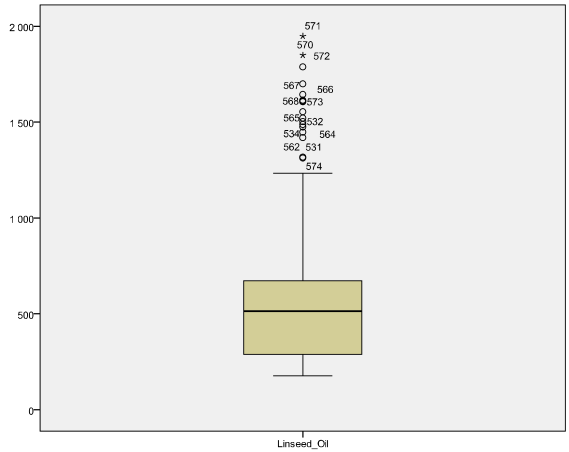


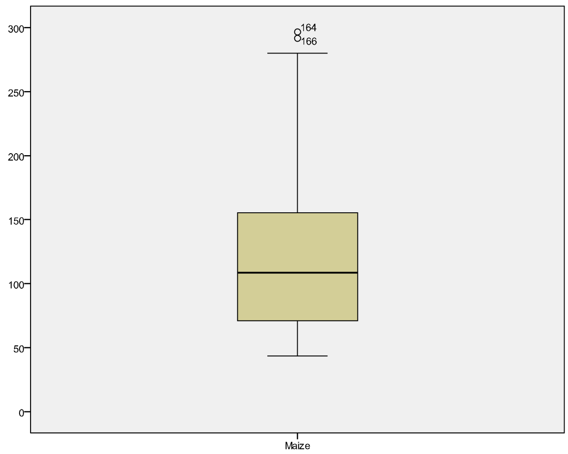


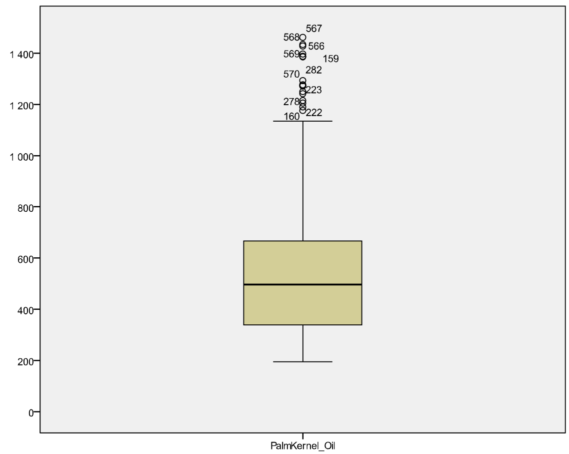

2 000
1 500
1 000
500
0
Cottonseed_Oil

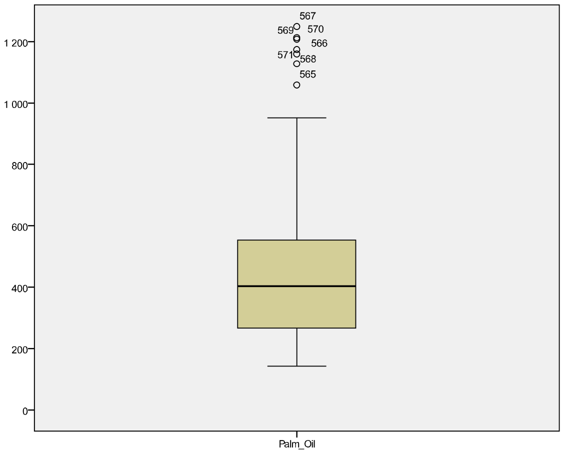

3 000
2 500
2 000
1 500
1 000
500
0
Groundnut_Oil

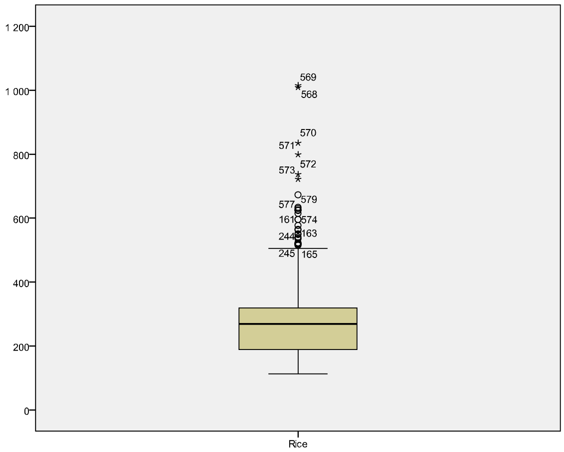

800
600
400
200
Jute


2 000
1 500
1 000
500
0
Linseed_Oil


300
250
200
150
100
50
0
Maize


1 400
1 200
1 000
800
600
400
200
0
PalmKernel_Oil


567
569
570
566
571
568
565
1 200
1 000
800
600
400
200
0
Palm_Oil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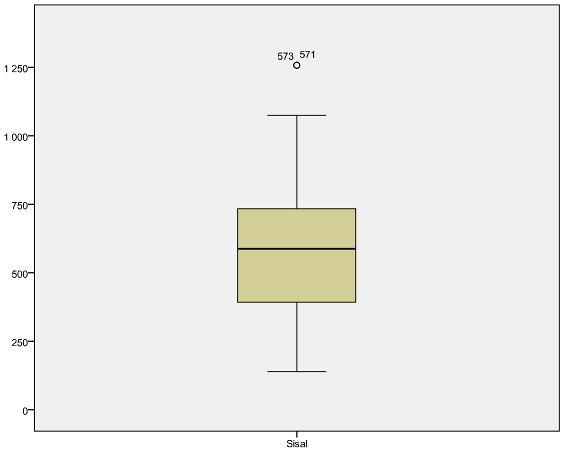
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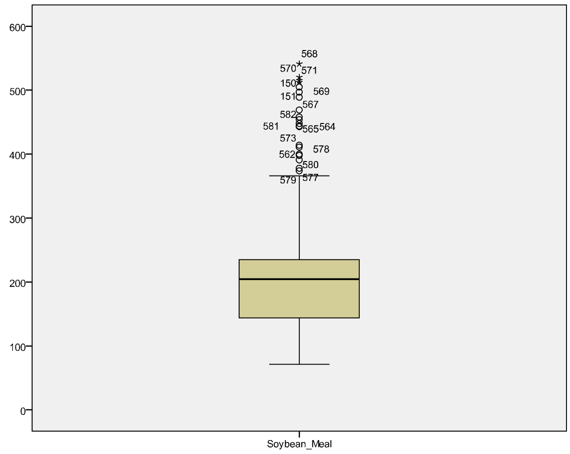
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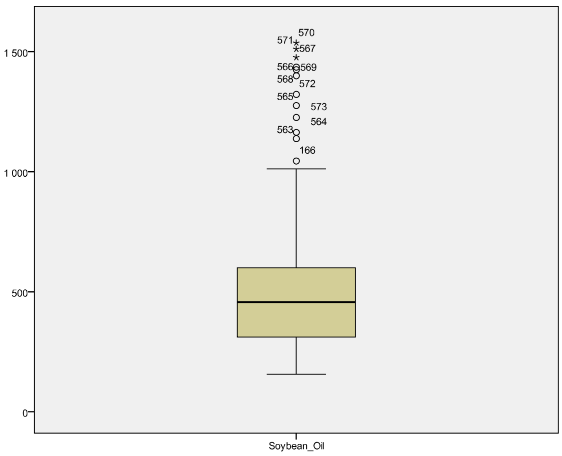
Soybean_Meal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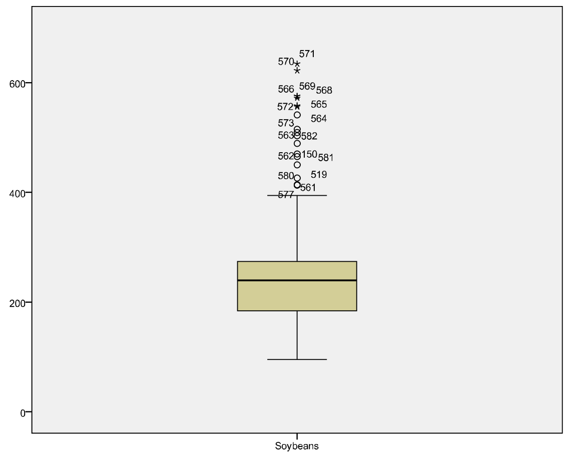
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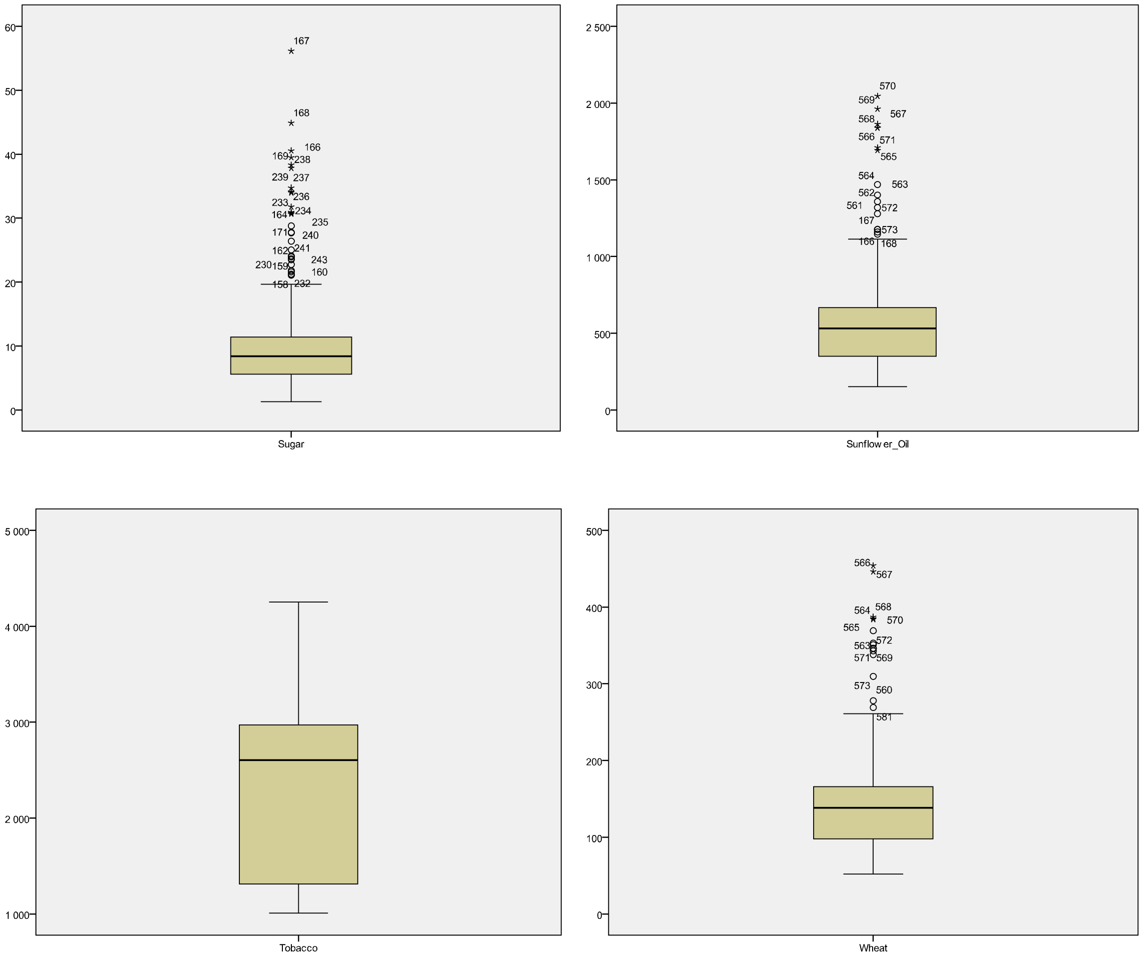
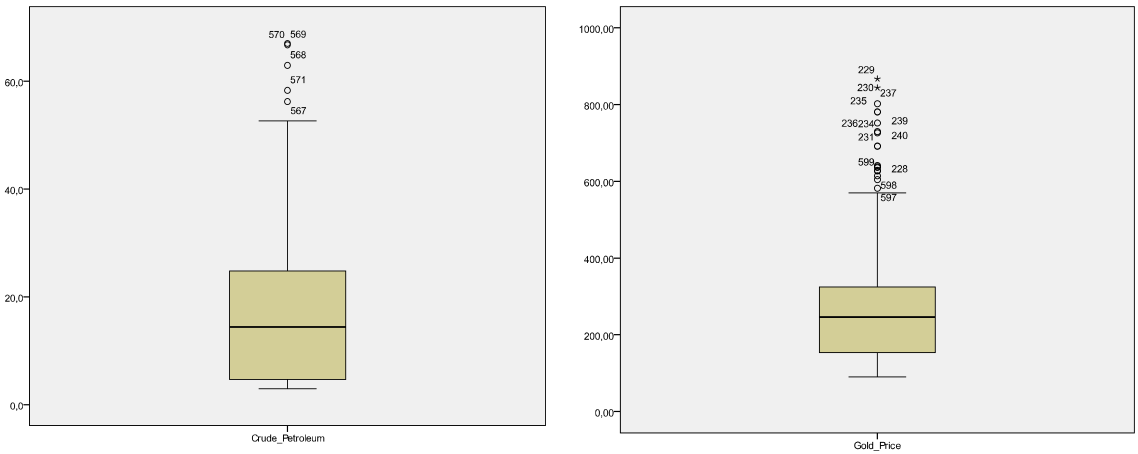
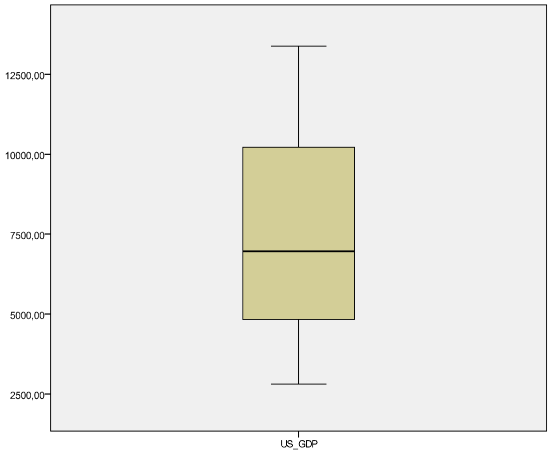


Figure_Apx 8 Box-Plots of Investigated Commodities

E.2 Explanatory Variables





Figure_Apx 9 Box-Plots of Variables

Appendix F Journal of Agricultural Economics Details

Journal of Agricultural Economics

Published on behalf of the Agricultural Economics Society

Edited by:
David Harvey

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