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ASSESSMENT OF POST-2003 CRUDE OIL PRICE HIKE THROUGH WAVELET COHERENCY ANALYSIS

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ABSTRACT Post-2003 hike and the resurgence after the global financial crisis of crude oil prices have drawn a great deal of attention from researchers and policy makers. Focusing on that episode, particularly around 2008, we contribute to the empirical literature with an aim to identify the co-movement patterns between oil price and its various determinants. For this purpose, we employ the continuous wavelet transformation based tools of coherence analysis. This allows us to track the co-movement in a time-varying fashion at different frequency bands between two variables. We consider the relation of oil prices with both real side factors and speculative financial activity. Our empirical findings are basically in line with the fundamentals approach and only point to ripple effects from the speculative activity. While the real side variables -especially OPEC (Organization of the Petroleum Exporting Countries) spare capacity and demand from emerging markets- become more coherent with the real WTI (West Texas Intermediate) oil price over the post-2003 period and climaxing around 2008, speculative activity fails to present any strong relation with the real WTI price. Coherence between speculative activity and oil price is evident only at very high frequencies and no significant co-movement is detected around 2008 period.
JEL C10, E32, Q41, Q43.
Keywords Oil price, Wavelet coherency, Speculation, Emerging markets

ÖZ Petrol fiyatlarının 2003 sonrası dönemdeki yükselişi ve küresel kriz sonrasında hızlı toparlanışı araştırmacıların ve politika yapıcıların dikkatini önemli ölçüde çekmiştir. Bu çalışma, özellikle 2008 yılı olmak üzere bu döneme odaklanıp, petrol fiyatları ile açıklayıcı değişkenleri arasındaki ortak hareketleri açığa çıkararak ampirik literatüre katkıda bulunmayı hedeflemektedir. Bu amaç için sürekli dalgacık dönüşümüne dayanan eşevrelilik analizine başvurulmuştur. Bu yöntem iki değişken arasında farklı frekans bantlarındaki ilişkinin zaman içinde değişen bir şekilde incelenmesine izin vermektedir. Petrol fiyatlarıyla hem reel unsurlar hem de spekülatif finansal faaliyetler arasındaki ilişki dikkate alınmıştır. Bulgular reel unsurların önemli olduğunu savunan görüşü desteklemekte olup, spekülatif faaliyetlerin sadece sınırlı dalgalanmalara neden olduğuna işaret etmektedir. Başta OPEC (Petrol İhraç eden Ülkeler Örgütü) atıl kapasitesi ve gelişmekte olan ülkeler talebi olmak üzere reel değişkenler WTI (West Texas Intermediate) petrol fiyatıyla 2003 sonrası dönemde (2008 yılı civarında daha da belirgin olmak üzere) daha eşevreli hale gelirken spekülatif faaliyet petrol fiyatıyla herhangi bir güçlü ilişki sergilememiştir. Petrol fiyatıyla spekülatif faaliyet arasında eşevreli hareket sadece çok yüksek frekanslarda mevcutken, 2008 yılında belirgin bir ortak hareket tespit edilememiştir.
2003 SONRASI HAM PETROL FİYAT ARTIŞLARININ DALGACIK EŞEVRELİLİK ANALİZİ İLE İNCELENMESİ
JEL C10, E32, Q41, Q43.
Anahtar Kelimeler Petrol fiyatı, Dalgacık eşevreliliği, Spekülasyon; Gelişmekte olan piyasalar

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1. Introduction

Post-2003 hike and the abrupt resurgence of crude oil prices after the global financial crisis, along with all industrial and consumable commodities, have drawn a great deal of attention from the academia as well as policy circles. Given that pre-2003 crude oil price hikes were mostly driven by supply-side issues such as geopolitical tensions, the recent tide caught many researchers and policymakers unprepared. For many researchers, crude oil prices were mainly responding to the surge in demand, particularly from emerging economies. Accordingly, unprecedented demand surge, coupled with a sluggish supply response, paved the way for tight markets.[1] For others, the increase in the crude oil price was higher than what fundamentals would suggest. The overlapping of the accelerated financial interest in commodity markets with price hikes led these researchers to associate these two developments.[2] Whether the speculative activity stemming from financial interest is the driving factor behind the oil price hike is a subject of unsettled academic debate.

Among the studies that focus on the price hikes over the post-2003 period, some provide evidence for the relevance of the fundamentals approach. Kilian and Hicks (2013) show that a substantial part of the increase in real oil prices is explained by growth surprises in emerging countries. Cevik and Sedik (2011) provide evidence for the recent price hike being due to cyclical factors originating particularly from the emerging world. Kaufmann et al. (2008) estimate an error-correction model and show that the relation between the capacity utilization rate and the crude oil price is non-linear.

Another strand of literature focuses specifically on the speculative activity and oil price relation. In this respect, Singleton (2013) shows that financial variables have an explanatory power on the excess returns of commodity futures. Tang and Xiong (2010) report a higher degree of correlation not only among commodities but also between commodities and equities. Irwin and Sanders (2010) test whether the positions of financial investors Granger cause the returns of futures contracts. For majority of the cases, they fail to reject that financial investors' positions do not Granger cause returns. Fattouh, Kilian, and Mahadeva (2013) thoroughly survey the literature, discuss the links between crude oil price increases and the financial interest, and provide an analytical framework for analysis. Overall, they conclude

[1] See, IMF (2005a) for an early assessment.
[2] See, for instance Masters (2008).

that fundamentals matter more and financial activity has a limited effect on spot prices.[3]

Lombardi and Van Robays (2011) point to fundamentals as accounting for a large portion of the price increases, while reporting that financial activity had short-lived effects on prices. Kilian and Murphy (2013) show that a great deal of variation in the real price of oil was due to the demand shocks while supply and speculative demand shocks played only a marginal role. Although Hamilton (2009) underlines the significance of fundamental variables, he also argues that the speculative activity may drift spot prices away from what fundamentals suggest. The key assumption is zero (or very low) price elasticity. However, Kilian and Murphy (2013) estimating a higher price elasticity than the earlier studies, break the link between spot prices and the speculative activity.

Building on the recent discussion, our main goal is to shed further light on what happened in the post-2003 period, particularly around 2008, via the following questions: Was it a bubble induced by financial players? Was the price of basic consumable commodity driven by self-fulfilling expectations independent of the fundamentals? Or, on the contrary, was it the fundamental variables backing the price movements as usual? Alternatively, are there any new variables capable of explaining the oil price hikes, or do the structure and the functional form of the relation between the oil price and its major determinants change in the meantime?

In this paper, we rely on coherence analysis based on continuous wavelet transformation. As it is a convenient tool to distinguish relations at particular frequencies and at particular time horizons, our approach has the potential to identify relations that get stronger or weaker over the time-frequency domain, considering the oil price. There are several applications of continuous wavelet coherency analysis to oil prices including Aguiar-Conraria and Soares (2011a), Tiwari (2013), Vacha and Barunik (2012). Meanwhile, Naccache (2011) and Benhmad (2013) focus on discrete wavelet analysis in order to study the cyclical behavior of oil price.

The fundamental variables that we employ in the wavelet coherency analysis are: the surplus capacity of OPEC countries, the US inventory level, demand measure from emerging countries, and US economic activity index. We also include net long position of non-commercial investors to check for speculative activity. The relation between financial interest and crude oil prices remains to be one of the most vibrant subjects with regard to commodity markets and merits further discussion. Our analysis differs from the studies utilizing wavelet coherency on the grounds that we consider the relation of oil prices with a large set of explanatory variables.

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[3] The literature on oil price and speculation relation has been extensively surveyed in Fattouh, Kilian, and Mahadeva (2013). Therefore the readers who are interested in this subject may refer to the mentioned study.

Our empirical findings are basically in line with the fundamentals approach. The spare capacity and emerging countries' demand measures appear to have become more coherent with the real oil price over the post-2003 period, climaxing around 2008. The US activity index also displays a pattern similar to these two variables. The inventory level is coherent with the real oil price at business cycle frequencies, as expected. On the other hand, speculative activity fails to present any strong relation with the real price. Sporadically, the coherence between these two variables gets firmer; however, this relation is observed only at very high frequencies. Moreover, no significant co-movement is detected between these two series around 2008 when price hikes became more pronounced.

The results of our study provide important policy implications. First, given that the correlation between financial speculation and crude oil prices is muted even during the period of unprecedented price hikes, policies targeted at regulating financial activity in commodity markets will have, at best, limited effects on prices. Second, the fundamental variables of supply and demand conditions should be carefully monitored, considering the changes in the composition of demand and supply. Oil demand of the developed world has almost reached the saturation level. On the other hand, demand from fast growing emerging markets is leading the growth in overall global oil demand. The correlation between oil prices and emerging economies' growth expanding over business cycle frequency when the global activity recorded strong performance suggests that careful studies are needed to project the growth potentials of emerging-market economies.

As shown in our analysis, crude oil price is highly correlated with the level of inventories at lower frequencies and with the level of spare capacity at business cycle frequency. These two findings underline the importance of both upstream and downstream investment and healthy supply of physical markets. However, in view of the recent projections by international organizations, unconventional oil sources will fall short of meeting the growing oil demand from emerging markets. Thus, conventional oil suppliers, especially OPEC countries, should take further steps to secure a relevant increase in production.

The rest of the paper is organized as follows: Section 2 presents the background of continuous wavelet transformation and the related tools, and describes the data. Empirical results and discussion are presented in Section 3. Finally, Section 4 concludes the study.

2. Methods

2.1. Co-movement in Time-Frequency Domain: Wavelet Coherency

The wavelet analysis considers time and frequency domains simultaneously, enabling a dynamic interpretation of how a variable behaves on different frequencies and how this behavior changes over time. The novelty of this approach is that the wavelet transform utilizes local base functions which can stretch in a flexible manner over the time and frequency domains. In this study, we will focus on the continuous wavelet transform analysis and use the wavelet coherency approach. The wavelet coherency basically provides information about how much two series are linearly correlated at a particular frequency and at a particular time locally in the time-frequency plane. Hence, it is possible to track how the correlation at various frequencies changes through time.

The wavelet coherency analysis has been applied to many diverse fields of studies. The earlier and pioneering examples include Torrence and Compo (1998) for geophysics, Torrence and Webster (1999) for meteorological studies, Grinsted et al (2004) for geographical studies and Cazelles et al (2008) for ecological time series among others. The number of economic applications of wavelet coherency analysis has increased in recent years [For instance, see Aguiar-Conraria et al (2008), Aguiar-Conraria and Soares (2011b), Rua (2010, 2012) and Caraiani (2012), Tiwari et al. (2014)].

In this study, we will focus on the continuous wavelet transform analysis and use its major tools: wavelet power, cross wavelet power, wavelet coherency.[4] The results of the empirical investigation are presented via plots of the wavelet coherency of oil price and related variables in pairs. The horizontal axis refers to time and the vertical axis refers to frequencies. The wavelet coherency shows the regions where two series co-move in the time-frequency domain. The warmer the color on the plot, the higher the co-movement is. The black solid line determines the regions where the coherency is statistically significant. The area outside the white dashed-line refers to the cone of influence.

2.2 Data

Data related to the inventory level, the OPEC surplus capacity and the spot West Texas Intermediate (WTI) price are received from the Short-Term Outlook Database of the US Department of Energy. The US National Activity Index and US consumer price index are obtained from the database-FRED of St. Louis Fed. Emerging countries' industrial production growth is calculated by the authors by using individual country data from Bloomberg and the World Bank. Finally, the net long position of non-commercial investors is calculated from CFTC (US Commodity Futures Trading Commission) data taken from Bloomberg.

The real WTI price is the spot price deflated by the US CPI (urban consumers, 1982-1984=100). EIA defines surplus oil production capacity as "potential oil production that could be brought online within 30 days and

[4] A detailed description of the continuous wavelet transform and the toolkit is presented in the Appendix.

sustained for at least 90 days, consistent with sound business practices".[5] The inventory level data includes both crude and oil products held by the private and public sectors of the US.

Demand measure of emerging countries is the monthly growth rate of the composite industrial production index of 14 leading non-oil producing countries, in which the industrial production figures are weighted by the PPP-adjusted (constant, 2005 US dollar) gross domestic product data.[6] The PPP-adjusted GDP data is obtained from the Global Development Finance database of the World Bank. The composite index is calculated by the authors. In addition, we also include an activity measure for the US, namely the Chicago Fed National Activity Index. This index is, by construction, an output gap measure. Finally, the speculative financial interest in oil markets is measured as the net long position of non-commercial investors as a share of total open positions, which is used in many studies such as IMF (2006). The data covers January 1994-December 2012 period at a monthly frequency.[7]

3. Results and Discussion

3.1. Evidence from Time Series Plots

The time series plots of the data are presented in Figure 1. Here, the real WTI price is plotted against the variables considered. First, we observe that the oil price and the OPEC spare capacity posit a negative relation. When the spare capacity hits a trough point, the oil price increases and generally reaches a local peak point. This relation is exclusively evident around mid-2008 when the OPEC spare capacity hit a point close to historical lows amid incessant demand from the emerging world and bleak supply outlook regarding the non-OPEC countries. For instance, Medium Term Oil Market Report of the IEA published in July 2008 when the crude oil prices hit historical high levels revealed that non-OPEC production headed for a dip in 2010-12. On the contrary, when spare capacity was close to its historic lows around 2004, IEA's Oil Market Report of August 2004 was expecting a 1.5-2 mb/d capacity surge.

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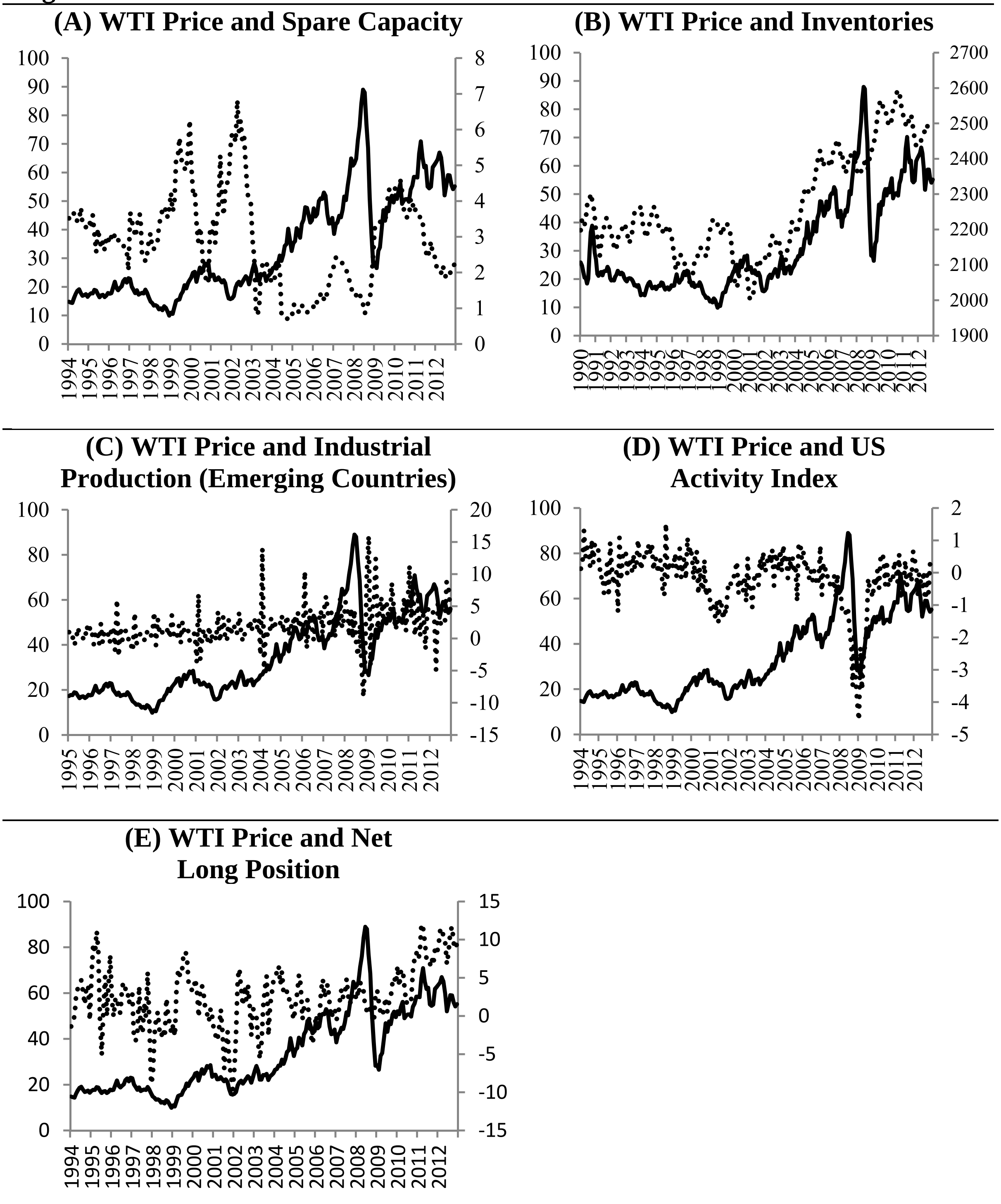
[5] The detailed definition can be found at http://www.eia.gov/analysis/requests/ndaa/.

[6] These countries are: China, Brazil, S. Korea, India, Turkey, Poland, S. Africa, Argentina, Thailand, Malaysia, Czech Republic, Colombia, Hungary, and Philippines.

[7] Although we focus on the post-2003 period in this study, we have tried to include data from earlier periods as much as possible. The main motivation is that longer time series enables us to extend our coherence analysis to lower frequencies. The main data restriction emerges from the fact that the OPEC surplus capacity data of the US Department of Energy is only available from 1994. Furthermore, the growth in industrial production series of emerging countries starts from 1995, as reliable data for those countries have been available since then. Finally, we extended inventory data back to 1990 in order to reveal the long term relation as this exception allowed us to investigate coherency at lower frequencies.

Figure 1. WTI Price and Selected Determinants



Notes: The left axis of each plot shows the Real WTI price (solid line), $ per barrel.

The right axis shows (dashed line):

(A) OPEC spare capacity, million barrels.

(B) Total inventories (US), million barrels.

(C) Emerging countries industrial production (m-m change).

(D) US National activity index.

(E) Net long position of non-commercial investors, % share of total open positions.

Inventory is accepted to be sine qua non for the commodity markets analysis. Inventory changes affect not only spot prices but also the shape of the yield curve through the convenience yield. The negative relation between the oil price and the inventory level appears to weaken starting from 2003, pointing to the importance of other variables. From this date through late-2006, when the first OPEC quota reduction took place, inventory accumulation became more apparent. The increase in inventories is moderate, however, when the inventory is measured as "the number of days it meets the forward demand". While total inventories corresponded to 61 days of forward demand in 2003, it rose to 67 days in 2008.[8] In this respect, the rise in inventories was not dramatic but only limited to one day of demand increase per year. Moreover, from mid-2007 until the outbreak of the global financial crisis, inventories remained flat below the levels reached in 2006. Over this relatively stable period, there was no considerable inventory build-up. Yet, crude oil prices surged substantially.

The growth of emerging countries' industrial production had an upward trend within the analysis period. While pre-2003 average annualized monthly increase was 5 percent, it rose to 9 percent between 2003 and 2012. Fast-growing emerging countries, particularly Asian countries, are argued to be the main driving factor behind the crude oil prices. During the analysis period, besides the strong growth record of the emerging world, the advanced countries also performed well. Since the WTI is a benchmark product priced in the US and the US demand is an essential factor, a closer look at the US economic activity would be useful in this respect. The crude oil price generally picks up when the activity is above the potential. When we focus on the period around 2008, it is also apparent that the activity measure had started falling from its peak level before the crude oil peaked.

Regarding the relation between speculative positions and the crude oil price, a few observations merit emphasis. First, net long positions appear to be more volatile than crude oil prices. Contrary to a clear increasing pattern in total open positions, the net long position of non-commercial investors appears to have swung heavily. Second, around mid-2008, net long positions do not display a clear co-movement with crude oil prices and the change in positions seems to be muted somewhat.

3.2. Evidence from the Wavelet Coherency Analysis

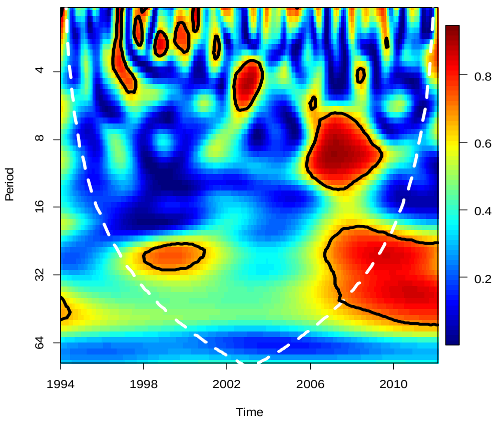
The price surge in the post-2003 period, which peaked at mid-2008, is of particular interest and the basic motivation for us. Given that the time series plots reveal only limited information, we turn to analyze the bivariate relations between the real WTI price and explanatory variables discussed in

[8] As the shale gas explorations surpassed what had been expected, the accumulation of inventories in the US accelerated again due to the export limitations, and in 2012 oil inventories matched up 79 days of forward demand. This development explains the recent divergence between Brent and WTI prices as well.

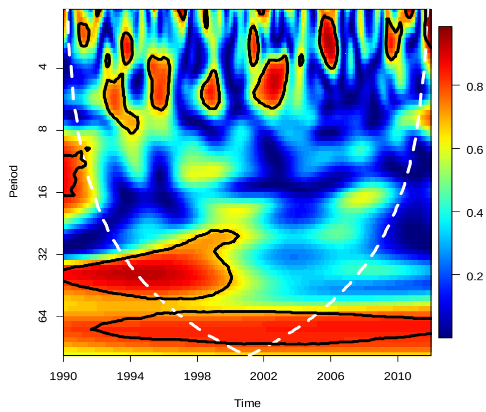
the literature from a time-frequency perspective. In this respect, Figure 2 presents the results of the wavelet coherency analysis.[9]

Figure 2: Wavelet Coherency of WTI Price and Selected Determinants

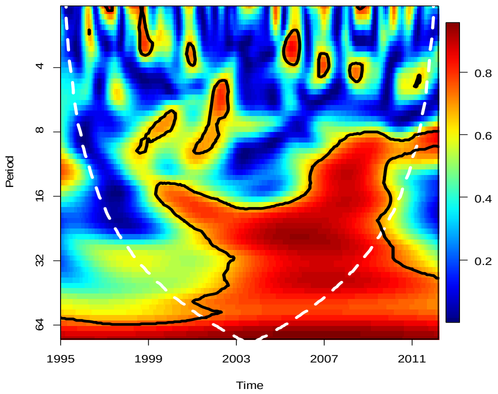
(A) WTI Price and Spare Capacity



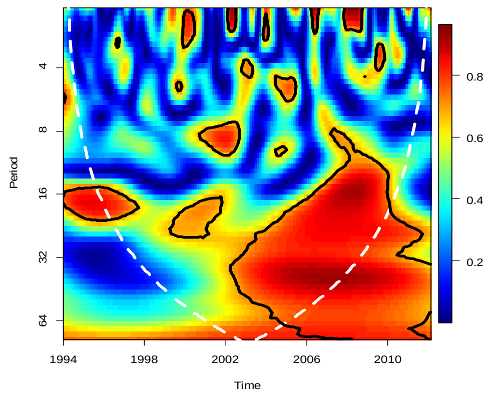
(B) WTI Price and Inventories



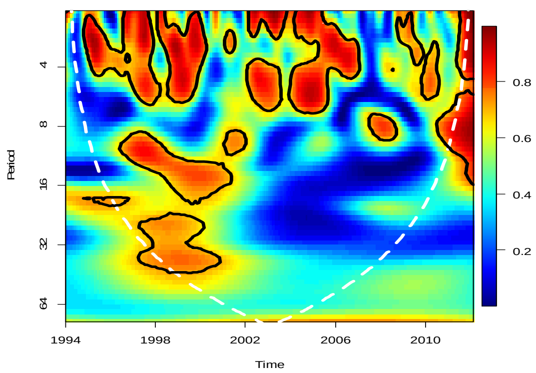
(C) WTI Price and Industrial Production (Emerging Countries)



(D) WTI Price and US Activity Index



(E) WTI Price and Net Long Position



Notes: The horizontal axis shows the time and the vertical axis shows the frequency in months. The warmer the color the higher the dependence is. The black contuar refers to statistically significant coherence and white-dashed line is the boundary of cone of influence.

[9] The empirical analysis is carried out by using the R package "biwavelet", written by Tarik C. Gouhier.

The analysis reveals that the OPEC spare capacity and the crude oil price have become significantly coherent at business cycle frequencies between 1.5 to 5 years, starting from 2006. Around the same period, a stronger relation seems to have taken place at high frequencies as well, reinforcing the importance of spare capacity on crude oil prices at 6-12 months frequency. Such a strong correlation between the oil price and the spare capacity has not been witnessed before. This relation, being more pronounced after 2007, might be an indication of the non-linear relation that Kaufmann et al (2008) aimed to capture. The increased and extended coherence after 2007 hints that the shrinkage of the spare capacity to historical lows amid the bleak supply outlook was associated with oil price hikes.

Considering the coherency of inventories and the crude oil price, two points become visible: The first one is the sporadic strong coherence at very high frequencies, specifically between 2-8 months. The more important case is the strong coherence at business cycles exceeding 64 months. The wavelet analysis confirms that the structure of the relation at lower frequencies was stable during the 2003-2008 period.

Emerging countries' growth and the real crude oil price appear to have been strongly coherent at business cycle frequencies lower than 64 months even before the recent tide started. However, the relatively short data available for the emerging world industrial production index prevents us from computing the relation for lower frequencies. Due to this fact, we cannot figure out whether this important relation continues at lower frequencies. The area of strong correlation has expanded to higher frequency bands in the post-2003 period, pointing to the increased importance of demand from emerging countries in oil price movements. This conclusion is consistent with the findings of Kilian and Hicks (2013) and Cevik and Sedik (2011). As discussed previously, these studies underscore the importance of the surge in demand arising from the emerging world. Likewise, the US activity and the real crude oil price also display strong and significant co-movement starting after 2002, particularly at business cycle frequencies as expected. This outcome supports the arguments in favor of demand-driven oil price movements. It should be reminded that the above-mentioned two studies also stress the relevance of demand developments across the advanced world.

As we have highlighted earlier, the association of crude oil price hikes with the financial interest is common. According to researchers who claim that the speculative activity was the main factor driving prices up, positions of non-commercial investors influence the futures prices and hence trigger the mechanisms that bring about effects in spot markets. Two channels are suggested: The first channel is the price discovery role, which implies the futures prices that respond to the positions of financial agents on future markets are followed by the spot markets mechanically. As discussed, Hamilton (2009) proposed a model and showed under which conditions such a mechanic relation can emerge. The second channel operates through inventory accumulation. This channel might be in effect either directly or indirectly. Direct effect is the inventory accumulation of both commercial and non-commercial agents to further squeeze the already tight markets. Indirect effect arises via the disturbances on the term structure caused by financial players. In other words, due to changes in net positions, the link between futures and spot prices break, futures prices diverge from spot prices and create arbitrage opportunities that can be exploited by taking positions both in physical and financial markets.

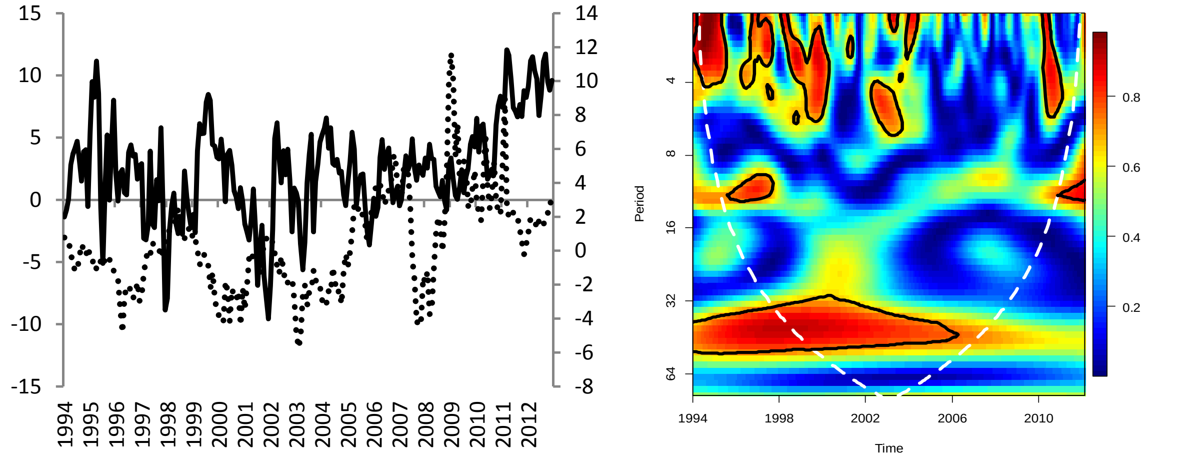
The evidence from the coherency analysis suggests that prior to 2008, net long positions and the crude oil price were only correlated at very high frequencies. Around 2008, when unprecedented price increases occurred, this correlation appears to have weakened, contrary to the arguments linking price increases to speculative interest. These findings indicate that we are not able to find evidence in favor of the price discovery role, the first channel we have discussed above. Besides, in addition to Irwin and Sanders (2010), Alquist and Gervais (2013) and earlier studies by the IMF (2005b, 2006) also investigate the casual relationship and conclude that causality runs from the prices to positions, providing further evidence against arguments supporting financial explanations.

The second channel, direct or indirect, works through inventory accumulation. If inventory accumulation had become more pronounced than before, we would have seen a stronger relation between these two variables. For instance, Krugman (2008) discusses this issue and concludes that such a surge in OECD inventory figures did not take place. Our finding regarding the coherence between crude oil prices and inventories does not suggest any structural change over the analysis period as well. Over the 2003-2008 period, crude oil prices and the inventory level neither became more coherent nor the relation spread to higher business cycle frequencies. Contrarily, the coherence at frequencies of 32-64 months seems to have disappeared around 2001. Lack of strong coherence between the net positions and spot prices coupled with unchanged relation between inventories and spot prices suggests that we fail to find any evidence that might link financial agents with physical markets.

In order to complete the analysis of the correlation between financial agents' positions and crude oil prices, the relation between net long positions and the term structure should also be investigated. The measure of term structure is the difference between the price of (6-month) futures contract and the spot price, which is called basis. Although the overall expectation is that both futures and spot prices respond to the same information set and the term structure is determined by the inventory level through the convenience yield, proponents of the speculation story claim that futures prices are influenced by the positions of financial agents. The time series plot and the coherency of basis and net positions are presented in Figure 3. The first striking issue is that throughout the 2003-2008 period, the basis takes both positive (term structure is sloped upwards, i.e. in contango) and negative (term structure is sloped downwards, i.e. in backwardation) values. In other words, financial agents, who have power to influence futures prices, preferred the positive basis (i.e. negative roll yield) for more than two years over the analysis period but they preferred the negative basis over the remaining period. The time series plot displays that the basis hits a local negative trough point in March 2003 and increases from this date onwards, crossing to the positive territory in March 2005. The basis keeps its upward trajectory until November 2006, just after the first OPEC quota decline, and then starts moving down again. The second remarkable issue is that the basis keeps decreasing after this date, gets back to the negative territory in July 2007 and remains there over the first five months of 2008, when price increases are the most dramatic. The coherence analysis, as well as the visual inspection of time-series, does not suggest a strong relation. Particularly, around 2008, the correlation is quite weak. The strong coherence at 32-64 month frequencies seems to have weakened starting from 2001 and disappear around 2006. Therefore, around 2008, we do not find a significant correlation not only between net-long positions and the spot crude oil price, but also between the basis and the net-long positions.

Figure 3: Net Long Positions of Non-commercials and Basis (6-month)

(A) Time Series Representation **(B) Wavelet Coherency**



Notes: The left axis of the plot shows the Net-long positions of non-commercials (solid line), % share of total open positions
The right axis shows (dashed line) the basis defined as the price of 6-month futures contract minus the spot price, $ per barrel.

Notes: The horizontal axis shows the time and the vertical axis shows the frequency in months. The warmer the color the higher the dependence is. The black contuar refers to statistically significant coherence and white-dashed line is the boundary of cone of influence.

To sum up, our findings suggest that the speculative activity and crude oil prices may be correlated only at high-frequencies, and financial agents may only be responsible for increased volatility. Overall, the evidence from the wavelet coherency analysis suggests that over the 2008 period, the oil price was strongly correlated with spare capacity and the emerging markets' demand over the business cycle frequency. Over the long term cycle, the oil price is strongly correlated with the inventories. Finally, there is no evidence of correlation between the net long positions of financial investors and the oil price around 2008. Our findings support the arguments in favor of real side variables rather than the speculative activity over the 2008 period.

4. Conclusions

Focusing on the post-2003 period and particularly the period around 2008, we aim to shed light on the unprecedented oil price movements. Employing the wavelet coherency analysis, we document the time and frequency varying nature of the co-movement between the oil price and its determinants.

This study confirms the view that supply and demand conditions (inventories, emerging market demand, and US activity) are more related to oil prices over the business cycle frequency. The results reveal that the oil demand from emerging markets has become increasingly important for spot prices, while their co-movement has also expanded to the business cycle frequency after 2006. In addition, our analysis emphasizes the emergence of spare capacity as a covariate of oil prices over the business cycle frequency, specifically during the price hikes of 2008 and around. Finally, the results show that the link between the crude oil price and the financial speculative activity is quite weak. Both of the channels, through which financial agents might have exerted pressure on crude oil prices, did not suggest a considerable association. Coherence analyses of the relation of crude oil prices and the basis with the net positions of non-commercial investors indicate that there exists a sporadic co-movement mostly at higher frequencies. Moreover, this correlation breaks down in the period around 2008. Our finding of weak coherence around this date provides contrary evidence to the claims that the price hike in the first half of 2008 of almost fifty per cent, without a major supply shock, was driven by the financial agents.

This study has important policy implications concerning the economic and financial forces behind the oil prices. First of all, we argue that regulatory policy actions on financial activity will have limited effects on oil prices due to the lack of a strong correlation between financial speculation and crude oil prices even at times of unprecedented price hikes. Contrarily, suppressing the activities of financial players may yield unintended consequences, e.g., commercial agents may consider the physical markets as the only option of hedging.

Second, the fundamental variables of supply and demand conditions should be carefully monitored. The oil demand of the developed world has almost reached the saturation level. On the other hand, demand from fast growing emerging markets is leading the growth in global oil demand. Especially, the ever-increasing energy demand has made China extremely influential in world energy markets. High population growth rate and the catch-up process of emerging market countries imply higher potential growth rate for these countries. So, another policy argument of our study is that solid projections of emerging markets' growth are needed in order to anticipate the future oil demand. In that regard, our policy recommendation is to focus on the factors of economic growth in such countries, including the investments in physical and human capital, technological progress, and the organization of productive activities.

We have found that the crude oil price is highly correlated with the level of inventories at lower frequencies. In addition, the correlation of oil price with the level of spare capacity seems to have strengthened at business cycles. These two findings underline the importance of both upstream and downstream investment and healthy supply of physical markets. In recent years, the increased supply from unconventional sources has helped keep prices stable, albeit at a high level due to the high marginal cost of production.

Considering the future path of supply, most recent projections by the International Energy Agency (IEA)[10] suggest that the new capacity boost from conventional sources of OPEC countries falls short of meeting the projected loss of matured areas of non-OPEC countries. IEA projections also suggest that the net marginal supply will stem only from deep-water conventional sources of Brazil and unconventional sources of oil, particularly from the US. Hamilton (2014)[11] emphasizes the risks arising from the rapid maturation of shale oil wells, which necessitates new diggings, as well as from the negative cash flows of firms. In this sense, the world's need for investment in conventional oil sources is still prominent. A demand shock and a lower-than-expected production from shale oil fields may leave the markets with diminished spare capacity, which has the potential to bring non-proportional effects on prices. In what follows, the OPEC supply should be closely monitored and relevant investment decisions should be made in view of the path of demand from emerging markets and the uncertain future of unconventional supply options. The experience of the last decade reminds us that investment decisions take considerable time to take effect. Postponed investment projects as a response to price falls in early-2000s are believed to be the main culprit of the tight markets in the pre-2008 period.

The results of the wavelet coherency analysis reveal that the level of the correlation between the oil price and its various determinants, in fact, changes over time and across frequencies. This breakdown of correlation is the major advantage of the wavelet methodology. With this breakdown, it is possible to provide guidance to researchers who aim to model the oil price behavior at different frequencies considering, at the same time, the changes in the structure of the relationship over time. Yet, the main caveat of this analysis is that it does not aim to provide a causal relationship.

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Appendix

Continuous Wavelet Transform and the Toolkit

Wavelet is a finite length and oscillatory real-valued function which is defined as:

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right) \tag{1}$$

The wavelet function has two parameters, τ and s. The translation parameter τ, determines the location in time and where the wavelet is centered. The scale parameter s, on the other hand, determines the width of the wavelet, showing whether the wavelet is stretched or dilated. In cases where $s < 1 (s > 1)$, the wavelet is compressed (stretched). Thus, at a lower scale, the compressed wavelet can detect higher frequencies of the series capturing the movements completed in very short terms. On the other hand, at a higher scale, the stretched wavelet can detect lower frequencies, capturing movements completed at longer terms. The $1/\sqrt{s}$ ensures energy normalization across different scales.

This basis function, commonly referred to as the mother wavelet, has to satisfy several conditions. The minimum of these conditions is that the $\psi(t)$ is square integrable and satisfies the admissibility condition: $0 < C_\psi = \int_0^{+\infty} \frac{|\hat{\psi}(\omega)|^2}{\omega} \mathrm{d}\omega < +\infty$ where $\hat{\psi}(\omega)$ is the Fourier transform of the wavelet.[12] The importance of the admissibility condition lies in the property that it enables the perfect reconstruction of the series from the wavelet transform. For many applications, this condition boils down to requiring $\int_0^{+\infty} \psi(t)\mathrm{d}t = 0$, implying that the wavelet has zero mean.[13] The wavelet is generally further restricted that its square integrates to 1, $\int_0^{+\infty} \psi^2(t)\mathrm{d}t = 1$, so that the wavelet is normalized to have unit energy. Hence, under these

[12] The Fourier transform of $\psi(t)$ is $\hat{\psi}(\omega) = \int_0^{+\infty} \psi(t) e^{-i\omega t}\mathrm{d}t$.

[13] As discussed in Aguiar-Conraria and Soares (2013), the square integrability is a condition needed for the function to have decay properties. Yet, in general, stricter decay conditions are imposed. The wavelet must be a well-localized function in the time and frequency domain so that it can provide a good time-frequency localization. For the functions that have sufficient decay, the admissibility condition is equivalent to requiring zero-mean property.

requirements, the function moves up and down around the time axis resembling a wave.

Among many different wavelet functions, the most commonly used one is the Morlet wavelet, especially in the applications to economic time series. The Morlet wavelet, being a complex wavelet and having imaginary and real parts, provides information on both the amplitude and phase in time. This property is especially useful for studying lead-lag behavior of the time series. The Morlet function is defined as:

$$\psi(t) = \pi^{-1/4} e^{i\omega_0 t} e^{-t^2/2} \quad (2)$$

where $\pi^{-1/4}$ is a normalization factor enabling the wavelet function to have unit energy.

The ω_0 parameter determines the wavenumber and thus the central frequency of the wavelet. There is a trade-off between time and frequency localization depending on the parameter ω_0. While a higher ω_0 enables a better frequency localization and a poorer time localization, a lower ω_0 provides a better time localization and a poorer frequency localization. Torrence and Compo (1998) show that when omega is equal to 6, the scale of the wavelet is almost equal to the Fourier period of the series, which makes the interpretation of the analysis easier. Hence, in this study, we use Morlet wavelet with central frequency equal to 6, as commonly used in economic applications [Vacha and Barunik (2012), Aguiar-Conraria et. al (2008), Rua (2010, 2012), Caraiani (2012), Rua and Nunes (2012) among others].

For a time series $x(t)$, the continuous wavelet transform $W_x(\tau, s)$ is the projection of a wavelet function onto $x(t)$ and is given by:

$$W_x(\tau, s) = \int_{-\infty}^{+\infty} x(t) \psi^*_{\tau,s}(t) \mathrm{d}t, \quad (3)$$

where * indicates the complex conjugate (see Torrence and Compo 1998). The continuous wavelet transform therefore decomposes a series over the time and frequency domain by using the basis wavelet functions originating from the mother wavelet described above. As the Morlet wavelet satisfies the admissibility condition, the decomposed series can perfectly be reconstructed. The use of finite length series in the computation of continuous wavelet transform introduces border effects. For the filters to calculate the values at the beginning and at the end of the time span, missing values should be artificially filled in. As discussed in Torrence and Compo (1998), the area which is subject to edge effects is called the cone of influence and the results in this area should be interpreted carefully.

The continuous wavelet transform analysis offers several tools to be used for univariate and bivariate analyses. The available tools are wavelet power, cross-wavelet transform and wavelet coherency.

The wavelet power spectrum, $|W_x(\tau,s)|^2$, measures the distribution of the spectral density of a series over the time-scale plane. In other words, it shows the relative contribution of variance at each time and scale to the total variance. Hence, if the wavelet power spectrum is double integrated over scale and time, the total variance of the series is reached, and thus the energy of the series is preserved. In a bivariate setting, for two time series, $x(t)$ and $y(t)$, it is possible to define the cross wavelet transform as follows:

$$W_{xy}(\tau,s) = W_x(\tau,s)W_y^*(\tau,s)\,. \tag{4}$$

Using wavelet power spectra of two time series and their cross wavelet spectrum, the squared wavelet coherency is defined as:

$$R^2(\tau,s) = \frac{\left|S(s^{-1}W_{xy}(\tau,s))\right|^2}{S(s^{-1}|W_x(\tau,s)|^2)S(s^{-1}|W_y(\tau,s)|^2)} \tag{5}$$

As described in Torrence and Webster 1999, the wavelet squared coherency is the absolute value squared of cross wavelet spectrum, which is normalized by the wavelet squared spectra of two time series. Here, $S(.)$ denotes smoothing operator in time and scale. The squared wavelet coherency shows how strong the relation between two series is across time and frequencies. The R^2 lies between 0 and 1; closer the value to 1, stronger the relation is. The wavelet coherency can be considered as a local correlation between two time series over time-frequency domain. Thus, plotting the wavelet coherency eventually reveals at what frequencies a relationship exists, how strong the relation is, and whether the frequency and the strength of the relation change over time. The wavelet coherency can detect significant coherence even though the common power of the series is low. To test the significance of the wavelet coherency, Monte Carlo methods are used as described in Grinsted et al (2004) and Torrence and Compo (1998).