The Effects of Oil Prices on the US Macroeconomy

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SCHOOL OF SCIENCE and TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Management

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THESSALONIKI – GREECE

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Abstract

The target of this dissertation is to investigate the consequences of oil price fluctuations on two macroeconomic variables, economic growth and inflation in United States (US, hereafter). The analysis takes place in both the time and the frequency domain and the results indicate that oil prices have a significant but declining effect on the economy. Impulse responses are employed in order to quantify these effects and the findings once again verify that any causality channel running from oil prices innovations to both economic growth and inflation have an unsubstantial impact.

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1. Introduction

The role of crude oil in the worldwide history is determinant. Its existence influences the worldwide economic conditions as it is one of the most important trading goods. Not only it constitutes a directly consumptive good, but it is also the first source for the production of various other useful products, such as gasoline. What is more, crude oil is directly associated with the human existence, an evidence of which is its massive consumption. However, its reserves are actually restricted as it is a depleting good that is also only locally produced in remote areas of the world, something that makes it much more valuable. Thus, the price of crude oil in combination with its supply and demand eruptions and oversupplies constitutes a matter of deeper investigation among worldwide communities. Crude oil prices can also have predictive power on various macroeconomic variables, as it is a key variable in most of the macroeconomic projections in the largest stock markets of the world. Furthermore, crude oil prices are of great importance especially to policymakers, central banks and international investors in sectors like shipping, aircrafts and energy industries. For all these reasons, crude oil prices and their evolution through the years affects all macroeconomic elements including inflation and growth rate, two basic macroeconomic tools that will be deeply analyzed in this paper.

The subject of this work is to detect the causality channels running among these three variables. These channels will be further studied in an attempt to identify the direct effects emerging from crude oil price changes on both inflation and economic growth as well as from inflation on economic growth. The dynamic linkages running between crude oil price variations and general macroeconomic activity is a critical issue that has been examined for the majority of the industrialized countries. Thus, for the purpose of this work the case of US is selected.

The methodology that is going to be used consists of two steps. Firstly, the causality channels will be identified through an analysis in the time domain proposed by Toda and Yamamoto (1995). Then, for the same objective, the analysis will take place in the frequency domain, as introduced by Breitung and Candelon (2006). This methodology will give a first glance as to identify whether the predictability is long- or short-term. Finally, in order to discriminate whether the obtained impacts have negative or positive and significant or insignificant effects, impulses will be imposed on the model and the corresponding responses will be recorded. The latter will be of two types, the common impulse responses and the impulse responses based on local projections introduced by Jorda (2005).

The results of the empirical analysis of the first two steps do not provide a definitive answer. The time domain analysis reveals a strong relation of crude oil prices and inflation with the economic growth. On the other hand, the frequency domain analysis rejects this hypothesis and reveals only important relationship between crude oil prices and inflation. As far as the nature of the effects is concerned, the impulse responses provide more consistent evidence. The Jorda (2005) method suggests that both inflation and economic growth have a lagged negative response on oil price crises which, however, last for mostly a couple of quarters. In relevance with the common impulse responses, they identify only significant and positive response of inflation to oil prices. It must be noted though, that this response is immediate and later on the future becomes negative, yet insignificant.

The dissertation is structured as follows. In chapter 2 a rather extensive literature review regarding the causation of crude oil prices with inflation and economic growth, as well as between inflation and economic growth is provided. In chapter 3 the different steps of methodology followed are theoretically analyzed and the data used are presented. In chapter 4 the results of the empirical analysis are provided along with their interpretation. Finally, the concluding remarks are presented in chapter 5.

2. Literature Review

There has been an extensive literature regarding the effects of oil prices on the macroeconomy of a country. One of the early attempts to assess them was the analysis by Nunnenkamp (1982) who focused on the negative effects for non-OPEC countries, both developed and developing, after the first oil price shock (1973-1979). The results indicated that, on average, a 10% increase in oil prices will decrease 2% the GPD growth. Later on, Estrada and Hernandez de Cos (2012) in their work tried to find a mathematical relationship for oil prices and GDP, through the Total Factor Productivity. As TFP is expressed in terms of GDP, they suggested that there is an indirect impact from oil prices on GDP. Their empirical analysis confirmed this suggestion and revealed a negative and significant coefficient, although its numerical value is rather small. A more thorough approach was contacted by Farhani (2012) who used a Dynamic Regression Model to identify the exact relationship in US economy by using both annual and quarterly data through 1960-2009. The results indicated that oil returns for annual data are insignificant and that have a negative effect on GDP, while quarterly have a positive and significant effect. The author extended his work by detecting the existing breakpoints and observed that they weaken the relationship between GDP and oil prices. As a final step, he used a VECM model and the results obtained suggested a stronger than before -yet still weak- relationship between GDP and oil prices.

Narayan *et al.* (2014) differed from the previous, in the sense that they tried to prove whether economic growth can be predicted through oil prices. They examined this in 45 countries, 17 developing and 28 developed. An important feature of this work was that the authors used both nominal and real oil prices, since they support that the policymakers should decide which price is more suitable. A first conclusion of their analysis suggested that nominal (73.33%) and real (66.67%) oil prices predict economic growth for an in sample-analysis.

However, the same did not occur for an out of sample analysis, as for nominal prices the percentage is still 70%, while in real prices, the amount equals to 55%. These results were obtained by following the Westerlund and Narayan (2012) methodology. Lewellen (2004) method provided few evidence of predictability, due to the fact that it does not take into consideration information in heteroscedasticity. In order to find out how prices affect economic growth, a bivariate GARCH VAR model was used. The results varied from country to country and whether nominal or real prices were used. For 23 out of 45 of the countries, nominal and real oil prices negatively affected GDP. The opposite was true for Netherlands, Italy, Finland and Australia. The results for Germany and Mexico revealed that although nominal oil prices had a negative relationship with economic growth, real oil prices had a positive one. For the rest 16 countries real oil prices indicated negative effects and nominal oil prices positive effects.

Doroodian and Boyd (2003) used a CGE model to investigate whether oil price shocks were still inflationary in the US economy by imposing an oil price innovation –similar in manner to that of 1973- at the year 2000. They examined this connection for the years from 1994 through 2020. The results from their analysis indicated that in the short-run CPI will diverge from its benchmark value, yet in the long-run it will converge to it, regardless of the technological advance and the current economic growth of US. The only difference was observed on the speed of adjustment which increased with higher technological advance and economic growth. These results were attributed to the fact that the US market has shifted from industrial to service oriented. Roeger (2005) in his work firstly identified the reason for the 2004 oil price rise and, then, continued by forecasting its effects on GDP and inflation in the EU area following the QUEST international macroeconomic model. The scenario Roeger followed is a pessimistic one that the oil shock will persist. As a result, GDP declined 0.5% in the short-run and in the long-run, considering the reduction of investments, this decline reached 1%. On the other hand, inflation rose in the beginning, but after the third quarter, inflation was kept under control.

Cunado and Perez de Gracia (2005) examined the relationship between oil prices innovations, GDP and CPI for six Asian countries through the period 1975-2002. In order to discriminate if the crisis was due to domestic or international economy, they used real and nominal world oil price. The latter was deflated in the respective currency. First of all, by following Phillips and Ouliaris (1990) as well as Gregory and Hansen (1996) tests, no long-run relationship between the variables was identified. Moreover, a unidirectional Granger causality emerged from deflated oil prices to inflation and when real oil prices were considered, the same relationship accrued only in Japan, Singapore and Thailand. Regarding the relationship between economic growth and oil prices, only deflated oil prices linearly Granger caused GDP in Japan and South Korea and non-linearly in Thailand. Finally, the authors examined the possibility of asymmetry between positive and negative changes of oil prices. They concluded that asymmetric relationship with economic growth existed only in South Korea when domestic currency was used, while for the inflation, asymmetric relationship was observed in South Korea and Malaysia.

Similar to this paper**,** Alvarez *et al.* (2011), examined the effects of oil prices on Spanish and the rest of euro area. Their approach differed in the sense that they estimated separately the first round –direct and indirect- and second round impacts. Through a theoretical analysis the authors supported that a direct impact of 10% increase in oil prices increases 2.1% and 1.7% inflation in Spain and euro area respectively, while indirect and secondary effects have an insignificant magnitude. Proceeding with empirical analysis, they used two models, MTBE and BEMOD. The analysis with the former model revealed that direct impacts will increase by 2.5% in 1 year in Spain and 2% in euro area. However, the indirect and secondary impacts became significant after the first year, although their quantitative effects were small. In the second year of an oil shock, the aggregated effects on GDP had their highest magnitude in Spain. On the other hand, the effects in EMU had their maximum impact during the first year. As for the second model, the results on inflation are similar but smaller. In addition to that, the impacts on GDP had a high lag due to the fact that the MTBE model is a backward looking model, while BEMOD is a forward looking one.

Gomez-Loscos *et al.* (2012) examined the effects of oil shocks on the macroeconomy of the G-7 countries, following the Qu and Perron (2007) model that allowed them to take into consideration any structural breaks of the oil prices. Three structural breaks were identified and their boundaries differed from country to country. For the first period, which covered the years 1973-1980/83, there was a negative effect on GDP for all the countries, yet significant only for Germany, Japan and UK. Oil prices affected positively the inflation, except Italy, but with significance only in US, Canada, France, U.K. and Italy. The results obtained in the second period, which covered 1987-1992, revealed positive effects on GDP, but significant only for Germany and Canada. The same occurred for inflation, with only difference that it is significant only in US and Japan. In the third period, 1995-2001, GDP is significantly affected again only for Germany (positive and low) and Canada (negative and high). Moreover, the impacts on inflation were significant and positive for Canada, Germany and Italy. For the last period which ended at 2008, significant effects of oil prices on GDP were found for France, Japan, Italy and UK and these effects were negative only for UK. Lastly, the connection between oil prices and inflation was positive and significant for all the G-7 countries. The authors, however, noted that the value of these effects was small and explained only a small part of their movement.

Yoshino and Taghizadesh-Hesary (2014) tried to quantify the effects of oil prices in GDP growth rates and inflation rates in US, Japan and China. In order to do so, they used a SVAR model and examined two periods. The first period covered the beginning of 2000 up to July of 2008 and the second from August of 2008 up to the end of 2013, that is before and after the Lehman shock. As far as

China was concerned, the impacts of oil prices on GDP and inflation rate stayed constant throughout the two periods. More specifically, for the two the elasticities were negative for GDP and positive for inflation, yet significant for GDP and only for the first period. However, the results on Japan were very different. Before the Lehman Brother crisis, the oil prices had a significant and positive effect on GDP and inflation. At the second period studied, the effects were negative, but significant only for GDP. The authors concluded by presenting the results for US. After the Lehman Brother crisis, the effects of oil prices fluctuations had an increased relation with GDP but a reduced one with inflation due to the lower aggregate demand.

Hsing (2007) in his work identified that there is a critical value at which the effects on the economy of a country switch from negative to positive and vice versa. Specifically, he examined German macroeconomy through years 1994 – 2004. The results indicated that inflation had always a negative impact on GDP. Conversely, oil prices had the same result only when they were higher than a certain critical value. Thus, when oil prices were below the aforementioned threshold they provided benefit for the German economy. The author with this analysis proved that rising oil prices not always had a negative impact on oil importing countries. In accordance with these result is the work of Ali-Al Zeaud (2014). He proved that GDP had a negative and weak dependency on oil prices for Jordan, although Jordan had a stunning of 96% of oil import dependency.

Cologni and Manera (2008) in their work presented the short-term impacts of oil prices on inflation and GDP of the G-7 countries through the period 1980-2003. Oil price changes directly affected real GDP in Canada and UK. On the other hand, they had significant and positive impact on all countries' inflation except UK and Japan. In order to quantify these effects, they proceeded with applying an innovation to the oil prices. In all the countries the effects faded away in a short period of time. More specifically, an oil price increase created an upward trend for inflation in all countries, whereas it had a significant impact on GDP only in the US and Italy. Chen (2009) in his work estimated the percentage of world average oil price pass-through into inflation for 19 countries from 1970 up to 2006. He observed that the long-run effects were much higher than the short-run for all the countries except Portugal. On average, a 100% increase in oil prices passed through as 17% increase in inflation in the long-run, while in the short-run the respective percentage is only 0.5%. Finally, the author identified a decreasing time varying trend of oil pass-through in all the countries, except Switzerland, with an average decline of 69.772%.

The causality channels running from inflation to economic growth have a major impact on the macroeconomy of the countries. Thus, it is essential to present literature regarding the effects of inflation on economic growth, as well. One of the early reports was that of De Gregorio (1992) whose analysis took place in 12 Latin America countries through 1950-1985. He found out that a 17% reduction in inflation rate had a significant positive impact on growth rate of 0.4%. These results were robust, as they remained the same even when hyperinflation and outliers were eliminated from the model. Moreover, Bruno and Easterly (1998) examined the course of economic growth during and after an inflation crisis. In a sample of 41 crises in 31 different countries throughout 1961-1994, they found out that in a period of crisis, GDP growth (-2.4%) was significantly lower than the average of the rest of the world, while after the crisis their growth (3.3%) was higher from their pre-crisis growth as well as the current average growth of the rest of the world. Omitting again outliers, the authors concluded that their results were robust. Valdovinos (2003) used the methodology of Lucas (1980) to identify a long-run relationship between inflation and economic growth from 1970 up to 2000 for eight Latin America countries. The data indicated a negative, yet insignificant relationship between the two variables. As a final step the author introduced a band pass low frequency filter to eliminate any seasonality of less than 8 periods, following Baxter and King (1995). As a result, the data presented a significant negative relationship with much higher magnitude.

Burdekin *et al.* (2004) followed a different approach to examine this relationship. They wanted to examine the point at which inflation had negative effect on GDP. Their sample consisted of 51 developing and 21 industrial countries for the periods 1967-1992 and 1965-1992, respectively. The results for the developed countries indicated that as long as inflation rate was below 8% there was a negative (-0.065) and insignificant effect on growth rate. Furthermore, once inflation was between 8% and 25% the impact continued to be negative (-0.310), yet significant. Finally, when inflation exceeded 25%, the effect remained the same, but with much higher magnitude (-1.713). As far as developing countries were concerned, when inflation rate was below 3% economic growth was positively (0.361) and significantly affected. However, when inflation was between 3% and 50%, the results indicated that a 1% increase in inflation will decrease growth by 0.083%. In addition, the results were insignificant and negative (-0.023) when inflation was between 50% and 102%, while if it exceeded the final threshold the effect became significant (-0.007). This linear estimation was measured without allowing for structural breaks. Consequently, the results underestimated the effects of inflation rate on economic growth for a factor of 1.5 for industrial countries and a factor over 5 for developing. As a last step, the same relationship was examined with a log model. It was noted that even though the results for industrial countries did not change substantially, the first threshold for developing countries was increased from 3% to 10%.

A similar analysis was contacted by Bick (2010) who followed an extension of Hansen's (1999) panel threshold model, by allowing for difference in the regimes' intercept as well. He used panel data for 40 countries from 1960 to 2004. The outcome of the model indicated that the hypothesis of one threshold cannot be rejected. The threshold in absence of regime intercept was 19% and, below it, there was a significant positive effect of inflation in economic growth. In contrast, above the specified threshold the impacts were negative and insignificant. The author proceeded by adding the regimes intercept and the threshold was decreased to 12%. Last but not least, when allowing for differences in the regime intercept the effects were doubled.

In the same manner, Lopez-Villavicencio and Mignon (2011) approach was consisted of a PSTR model, as it allowed the smooth transition from one regime to another. The analysis took place for 44 countries, both developed and developing, from 1961-2007. They began by estimating for the whole set of countries, without discriminating their economic situation. The results indicated that there is no linearity in the effects of inflation. Specifically, if inflation was below 15% there was no effect on economic growth, whatsoever. On the contrary, once inflation exceeded this value, it had a significant and negative influence on GDP, as an increase of 1% decreases GDP per capita growth by 0.75% (ceteris paribus). The authors proceeded with identifying 3 regimes (1961-1965, 1981-1985 and 2001-2005), and afterwards they analyzed each one of them for a selection of countries according to their economic situation. The obtained results for the emerging economies revealed a negative relationship, no matter the level of inflation. The same occurred for the developed countries, with the exception that at the last regime the effects were positive. Additionally, they extended the sample by including all countries. A threshold for both groups was identified at which the impacts of inflation change. This threshold for the developed countries (1.2%) was much lower than the respective one of the developing (14.5%). Inflation for the developed countries had a positive effect on GDP when it was below the threshold, while for the developing countries had no effect at all. Above the respective threshold, the effects became negative for all countries. In order to test for the robustness of their results, the authors used a GMM to validate the estimations. The results remained, with small differences, the same in the threshold values (1.2% and 17.5% respectively) and so did the effects.

Mallik and Chowdhury (2001) proved that inflation with economic growth in Bangladesh, India, Pakistan and Sri Lanka had a strong positive relationship and that a change in growth rate had a higher impact on inflation rate than the opposite. Hwang (2007) used a full-fledged VARMA(2,2)-M-Asymmetric GARCH(1,1) with lagged variables model in order to capture the direction of causality between inflation and economic growth in US throughout January 1947 – March 2005. He found out that this model was better fitted than any other symmetric and asymmetric models (GARCH, GARCHM and GARCHML). His study considered monthly data for US from January 1947 through March 2005. The coefficients of the AR model revealed a negative and significant correlation from inflation to real growth, whereas the opposite was insignificant. Last but not least, his model indicated that high volatility in inflation resulted in high volatility in real growth, while the converse had less magnitude even than that of the influence of inflation to real growth.

Erbaykal and Okuyan (2008) examined the same relationship in Turkey from January 1987 through the second quarter of 2006. After the presence of cointegration was confirmed from a UECM model by a Bound Test developed by Perasan *et al.* (2001), an Autoregressive Distribution Lag (ARDL) model was used to determine the long- and short-run relationship of the variables. It was observed that even though there was no significant long-term relationship, there was a strong negative and significant short-term relationship between inflation and economic growth. Their final step was to identify the direction of the causality. In order to do that, they used a Seemingly Unrelated Regression (SUR) that verified a unidirectional causality from inflation to economic growth.

Alexander (1997) took into consideration that at least real capital and labor inputs contributed to the correct specification of a model. His model consisted of a combined time series of eleven OECD countries through the years 1966-1988, but the best specified model was the one that consisted of any sub-sample of ten countries. At the complete combined series regression, inflation and its first difference were both significant and negative and the model was best fitted, when both of them were taken into the equation. To detect problems in case of omitted variables the author re-estimated the model by adding government consumption and exports. The results were again the same, leading to the conclusion that once real capital and labor inputs had been appropriately proxied in the model the results will be robust.

To sum up, it can be concluded that the existing literature is in consensus regarding the effects of crude oil prices' fluctuations on the macroeconomic variables examined in this study. First of all, there is a significant and negative impact on the economic growth of a country. However, this impact is of small magnitude even for oil importing countries and it has a declining importance after the first oil crisis of 1973. Furthermore, the same findings occur for the inflation, though the effects result in the increase of inflation and not in its reduction. Likewise, the various works on the effects of inflation on economic growth have common results. For each country, exists a threshold which below it any variations of inflation has no or positive effects on economic growth. In contrary, above this threshold a change in inflation will result in a reduction of economic growth.

3. Methodology and Data

3.1. Methodology

As a first step in the identification of causality among the data, it is essential to confirm that they are stationary in order to avoid a spurious regression. For this reason, three different tests are applied to identify the order of integration of the variables. These tests are the Augmented Dickey-Fuller (ADF) test, the Dickey Fuller test using generalized least square (DF-GLS) and the Phillips Perron test (PP).

The ADF test was developed by Said and Dickey (1984). The null hypothesis of this test is the existence of a unit root at a time series y_t, while the alternative suggests its stationarity. The ADF test requires that y_t follows an ARMA (p,q) structure and examines whether $\varphi = 1$:

$$y_t = \beta' * D_t + \varphi * y_{t-1} + \sum_{j=1}^{p} \psi_j * \Delta y_{t-1} + \varepsilon_t \quad (1)$$

where D_t is a vector of deterministic terms (constant, trend etc.), Δy_{t-j} are used to approximate the ARMA structure of the errors, the value of p is set so that the error ε_t is serially uncorrelated which is also assumed to be homoscedastic.

An important issue is the number of lags for the AR model. If the chosen value is too large, the power of the test will decrease. By contrast, if it is too small, the remaining serial correlation in the error term will bias the test. The most common criteria used to choose the correct number of lags are that of Akaike (AIC) and Schwarz Bayesian (SBIC) information criteria.

The PP test differs from the ADF test in the way it deals with heteroscedasticity and serial correlation in the error term. It ignores them at the regression and corrects for their presence directly at the t-statistic. As a result, the PP test is robust to general forms of heteroscedasticity. The regression of this test is:

$$\Delta y_t = \beta' * D_t + \pi * y_{t-1} + u_t \quad (2)$$

The null hypothesis of this test again suggests a unit root test, that is $\pi = 0$. Finally, for the PP test there is no need to specify the lag length of the regression and it can identify unit roots correctly even in the presence of structural breaks.

Elliot, Rothenberg and Stock constructed an efficient version of the ADF test-statistic, the DF-GLS. The first step is to construct detrended data with the help of the trend parameter $\hat{\beta}_{\overline{\varphi}}$:

$$y_t^d = y_t - \hat{\beta}'_{\overline{\varphi}} * D_t \quad (3)$$

The next step involves the estimation of the ADF test regression using the GLS detrended data, which results in eliminating the deterministic term:

$$\Delta y_t^d = \pi * y_{t-1}^d + \sum_{j=1}^{p} \psi_j * \Delta y_{t-j}^d + \varepsilon_t \quad (4)$$

The null hypothesis of unit root tests whether $\pi = 0$. This test has higher power than the ADF and PP test when φ is close to unity and thus, it is called an efficient unit root test.

After the order of integration of the variables has been confirmed, linear causality is tested with the Toda and Yamamoto (1995) method. The rationale of this model is as follows:

Assume a time series y_t with error term η_t that is a vector AR(k) model integrated of order d.

$$y_t = \beta_0 + \beta_1 * t + \cdots + \beta_q * t^q + \eta_t \quad (5)$$

$$\eta_t = J_1 * \eta_{t-1} + \cdots + J_k y \eta_{t-k} + \varepsilon_t \quad (6)$$

If (2) is substituted in (1), and after calculations it is proven that:

$$y_t = \gamma_0 + \gamma_1 * t + \cdots + \gamma_q * t^q + J_1 * y_{t-1} + \cdots + J_k * y_{t-k} + \varepsilon_t \quad (7)$$

This method is interested in the significance of the lagged values of (7). As a result, the null hypothesis examines whether $J_1 = J_2 = \cdots = J_k = 0$. Considering that k is the optimum lag length, then, the coefficients of higher lagged values are statistically equal to 0 and thus without loss of generality (7) can be transformed into:

$$\widehat{y_t} = \widehat{\gamma_0} + \widehat{\gamma_1} * t + \cdots + \widehat{\gamma_q} * t^q + \widehat{J_1} * y_{t-1} + \cdots + \widehat{J_k} * y_{t-k} + \hat{J}_p * y_{t-p} + \widehat{\varepsilon_t} \quad (8)$$

where $p = k + d$ and the circumflex denotes estimation with OLS. Under the null hypothesis, the Wald statistic is asymptotically distributed as chi-square with m degrees of freedom ignoring whether y_t is cointegrated or not, as well as its order of integration. It is, however, of utmost importance to define correctly the optimal lag length of y_t, as well as its order of integration. Thus, for the former the AIC or SBIC are used, while the usual unit root tests are applied for the latter.

The next step of this study is to examine the causality in the frequency domain, following the Breitung and Candelon (2006). This method assumes a bivariate model of finite-order, of the form:

$$\Theta(L)z_t = \varepsilon_t \quad (9)$$

with $\Theta(L) = I - \Theta_1 * L - \cdots - \Theta_p * L^p$, $z_t = [x_t, y_t]'$, $L^k * z_t = z_{t-k}$ and ε_t a white noise error term. When the system is assumed to be stationary, then, it has a MA representation:

$$z_t = \Phi(L)\varepsilon_t = \Psi(L) * \eta_t \quad (10)$$

with $\Phi(L) = \Theta(L)^{-1}$ and $\Psi(L) = \Phi(L) * G^{-1}$ and G is the lower triangular matrix of Cholesky decomposition. To test for causality, they use the method of Geweke (1982) and Hosoya (1991), that is:

$$M_{y \to x}(\omega) = \log\left[1 + \frac{\left|\Psi_{12}\left(e^{-i\omega}\right)\right|^2}{\left|\Psi_{11}\left(e^{-i\omega}\right)\right|^2}\right] \quad (11)$$

The null hypothesis of no causality from y to x must satisfy that $\left|\Psi_{12}\left(e^{-i\omega}\right)\right|^2 = 0$. However, $\left|\Psi_{12}\left(e^{-i\omega}\right)\right|^2$ is a complicated non-linear function and as a result it is hard to estimate it. To make it simpler, and considering that $\Psi(L) = \Phi(L) * G^{-1}$, Ψ_{12} can be written as :

$$\Psi_{12}(L) = -\frac{g^{22} * \Theta(L)}{|\Theta(L)|} \quad (12)$$

where g^{22} is the lower diagonal element of G^{-1} and $|\Theta(L)|$ is the determinant of $\Theta(L)$. Thus, for y not to cause x at frequency ω must be satisfied that:

$$|\Theta_{12}(e^{-i\omega})| = |\sum_{k=1}^{p} \theta_{12,k} \cos(k\omega) - \sum_{k=1}^{p} \theta_{12,k} \sin(k\omega) * i = 0 \quad (13)$$

At the final step, they assume that $\beta_j = \theta_{12,j}$ and the null hypothesis of no causation can be test as

$$R(\omega) * \beta = 0 \quad (14)$$

where $\beta = [\beta_1, \dots, \beta_p]'$ and $R(\omega) = \begin{bmatrix} \cos(\omega) & \cos(2\omega) & \dots & \cos(p\omega) \\ \sin(\omega) & \sin(2\omega) & \dots & \sin(p\omega) \end{bmatrix}$ (15)

The advantages of this methodology lie in the fact that it can identify whether a relationship is short- or long-term and it has high power for causality in the presence of non-linearity. Furthermore, it can even identify causality that in the time domain cannot be identified. Finally, the test can be easily extended by including more variables, stationary or not and even cointegrated among each other avoiding the potential problems of a spurious regression.

The final step of this work consists of imposing an impulse in the causing variables and examines the response of the targeted variables, as it is interesting to identify whether the causal variable has a positive or a negative impact on the target variable. Two types of impulses are used. The common impulse response and the impulse response based on local projections introduced by Jorda (2005). The response can be measured through the impulse response function (IRF), which is:

$$IRF(t, h, d_i) = E\left(y_{t+h} \middle| u_{t+j} = \begin{cases} d_i \ if \ j = 0 \\ 0 \ if \ j \in (1, h) \end{cases}; \|_t\right) - E\left(y_{t+h} \middle| u_{t+j} = 0 \ \forall j \in (0, h); \|_t\right) \quad (16)$$

where, h is the horizon at which the response is estimated, d_i the disturbance vector of dimension equal to the number of variables examined and $\|_t$ the information available at time t.

The method of common impulse responses is applied as follows. Consider a simple bivariate VAR(1) model:

$$y_{1t} = b_{10} + b_{11} * y_{1t-1} + a_{11} * y_{2t-1} + u_{1t} \quad (17)$$

$$y_{2t} = b_{20} + b_{21} * y_{2t-1} + a_{21} * y_{1t-1} + u_{2t} \quad (18)$$

where u_{it} is an i.i.d. disturbance term with $E(u_{it}) = 0$ and $E(u_{1t} * u_{2t}) = 0$. Impulse responses trace out the responsiveness of the dependent variables in the VAR to shocks to the error term. A change in u_{1t} will directly affect the value of y_{1t}, which in its turn, it will influence in the next period the value of y_{2t} and vice versa. A shock is applied to a causing variable and the length and the magnitude of the effects on a target variable are recorded. If a response is equal to zero, then the shocked variable does not Granger-cause the under examination variable.

To measure the IRF of the model, the VAR(p) model is transformed to a VMA(∞):

$$y_t = \bar{y} + M(L)u_t \quad (19)$$

with $M(L) = I + M_1L + M_2L^2 + \cdots$

Then, this representation can be split into pre-shock, shock and post-shock components as follows:

$$y_{t+h} = \bar{y} + \sum_{s=h+1}^{\infty} M_s * L^s * u_{t+h-s} + M_h * u_t + \sum_{s=0}^{h-1} M_s * L^s * u_{t+h-s} \quad (20)$$

Finally, the IRF is computed by having in mind its definition and it is equal to:

$$IRF(t, h, d_i) = M_h * d_i \quad (21)$$

However, this method is optimum for all horizons only in the case that the VAR model coincides with the data generating process (DGP). If that is not the case, then the computed IRF will be biased and as the horizon increases the accuracy of the IRF's deteriorates.

Impulse responses based on local projections are more robust on the misspecification of the DGP. In his work, Jorda (2005) proposes the estimation of IRF for each new horizon h separately. This is achieved by regressing the depending variables at horizon $t + h$ on the information set at time t, such as:

$$y_{t+h} = a^h + P_1^{h+1} * y_t + \cdots + P_p^h * y_{t-p+1} + u_{t+h} \quad (22)$$

for $h = 0,1,\dots,H$ and with $P_1^0 = I$. From this equation and considering the definition of IRF's, the local projections IRF's can be computed as follows:

$$LPIRF(t,h,d_i) = E\{a^h + P_1^h * [a^0 + P_1^0 * y_{t-1} + \cdots + P_p^0 * y_{t-h-p+1} + d_i] + \cdots + P_p^h * y_{t-p+1}\} - E\{a^h + P_1^h * [a^0 + P_1^0 * y_{t-1} + \cdots + P_p^0 * y_{t-h-p+1} + 0] + \cdots + P_p^h * y_{t-p+1}\} (23)$$

This method is used as it has significant advantages over the common impulse response. Besides the robustness on the misspecification of the unknown DGP, it can be estimated with simple least squares. Furthermore, for its calculation, asymptotic delta-method approximations are not required. Finally, it can be implemented in highly non-linear models.

3.2. Data

The variables that are used are the real GDP of US in billions of 2009 chained US dollars, the oil prices of WTI Cushing Oklahoma in US dollars per barrel and the CPI of US and they are presented analytically in figures 1, 2 and 3, respectively. Furthermore, the data are quarterly through the period 1986Q1-2015Q1 and they have been obtained from the Federal Reserve Economic database of US. It should be noted that real prices are used and, thus, the crude oil is transformed from nominal to real by dividing the price with the respective CPI, that is:

$$real\ crude\ oil\ prices_i = \frac{nominal\ crude\ oil\ prices_i}{cpi_i} \quad (24)$$

where i denotes the respective observation.

Following the aforementioned methodology, firstly the stationarity of the variables is tested, interested at the 5% level of significance. A clear trend is observed at their graphical representation, in the Figures 1, 2 and 3, suggesting that all the variables have at least one unit root.

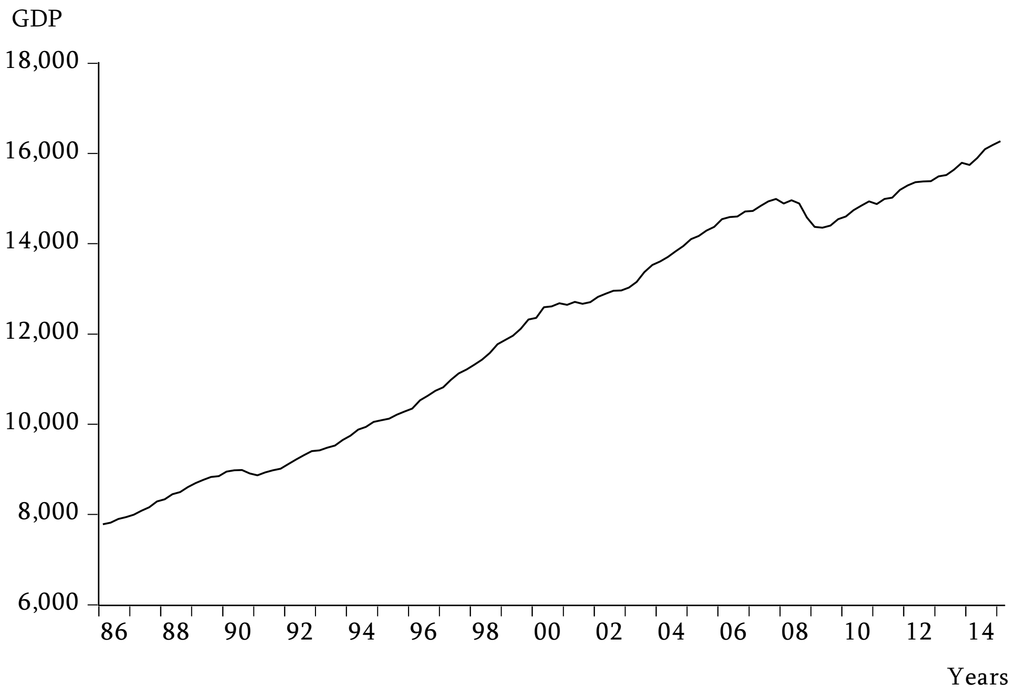

Figure 1. real GDP

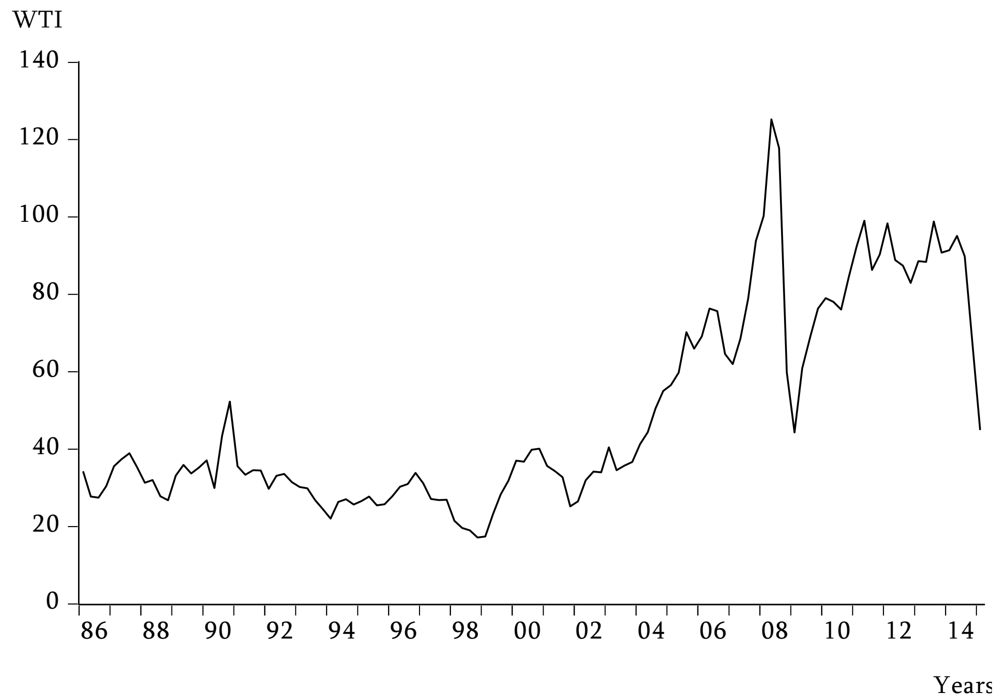

Figure 2. real WTI prices

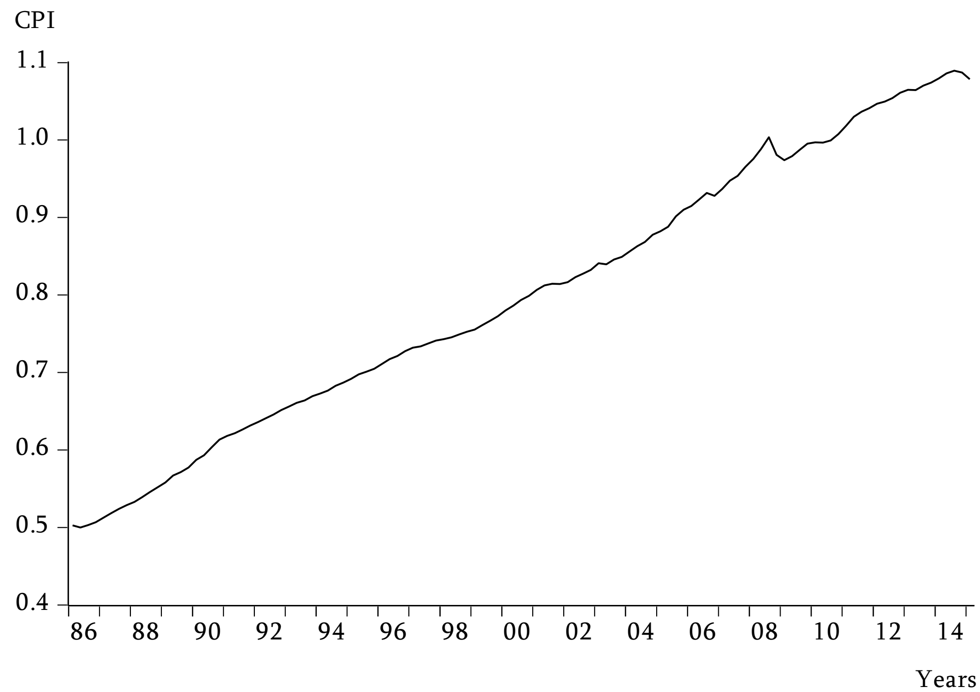

Figure 3. CPI

In order to confirm the presence of the unit roots, all three tests (ADF, DF-GLS, and PP) are applied. The variables are tested firstly including only intercept and then adding a trend as well.

Table 1: ADF unit root test

Variables	no-trend	trend
	p-value	p-value
GDP	0.8797	0.8197
WTI	0.4449	0.3507
CPI	0.7161	0.2852

Firstly, for the ADF unit root test the p-values in all cases are higher than 0.05. As a result, the null hypothesis of no stationarity cannot be rejected.

Table 2: DF-GLS unit root test

Variables	no-trend	trend
	t-Stat.	t-Stat.
GDP	1.697563	-1.557802
WTI	-1.445956	-2.260677
CPI	2.305440	-2.777998

The critical value of t-statistic when a trend is not including is -1.943, while when a trend is taken into consideration is -3.016. Comparing these values with the respective t-Statistics, displayed at table 2, GDP and WTI fail to reject the null hypothesis of a unit root for both cases, while CPI rejects the null hypothesis in the no trend case. The results indicate again, that all the variables have at least one unit root.

Table 3: PP unit root test

Variables	no-trend	trend
	p-value	p-value
GDP	0.8944	0.7908
WTI	0.4446	0.3864
CPI	0.8229	0.4815

Finally, the p-values of the PP unit root test are, again, higher than 0.05 and the null hypothesis of no stationarity cannot be rejected. Therefore, it is safe to conclude that all the variables have at least one unit root.

However, it is essential to confirm the exact number of unit roots and thus, the first differences of the variables are tested for stationarity. To remove any seasonal effects the annualized growth of each variable as:

$$growth\_Y = \frac{Y - Y(-4)}{Y(-4)} \quad (25)$$

where $growth\_Y$ is the first difference of each variable, Y is the current value of the variables and $Y(-4)$ is the value 4 observations (quarters) earlier.

This time, the graphical representation of the variables, presented in the Figures 4, 5 and 6, indicates stationarity.

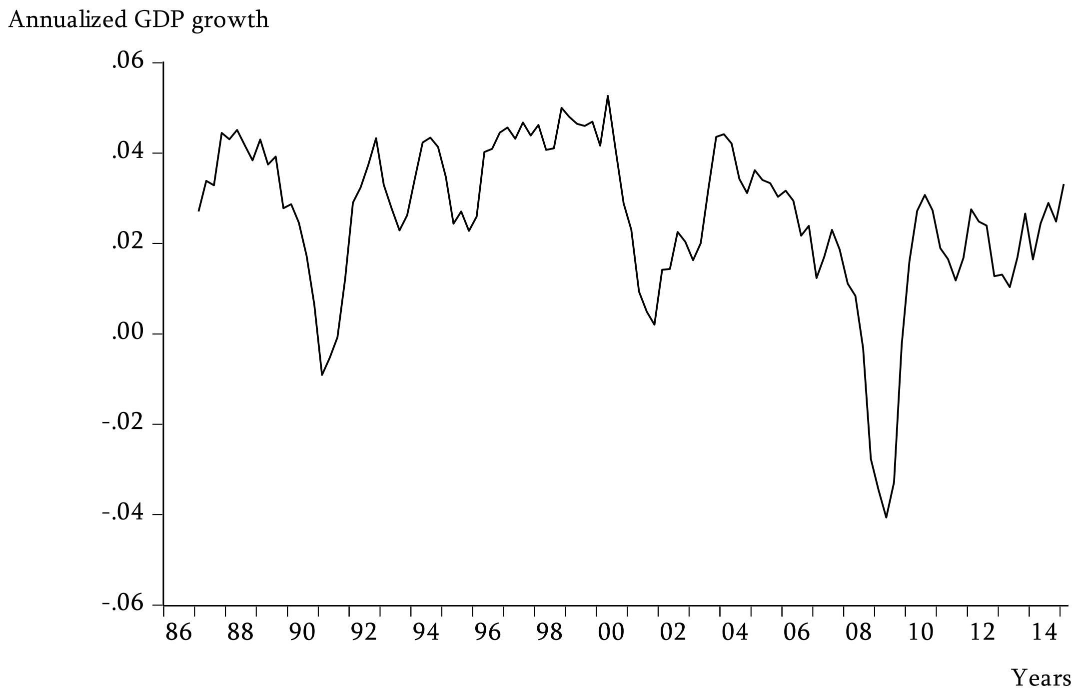

Figure 4. Annualized growth rate of GDP

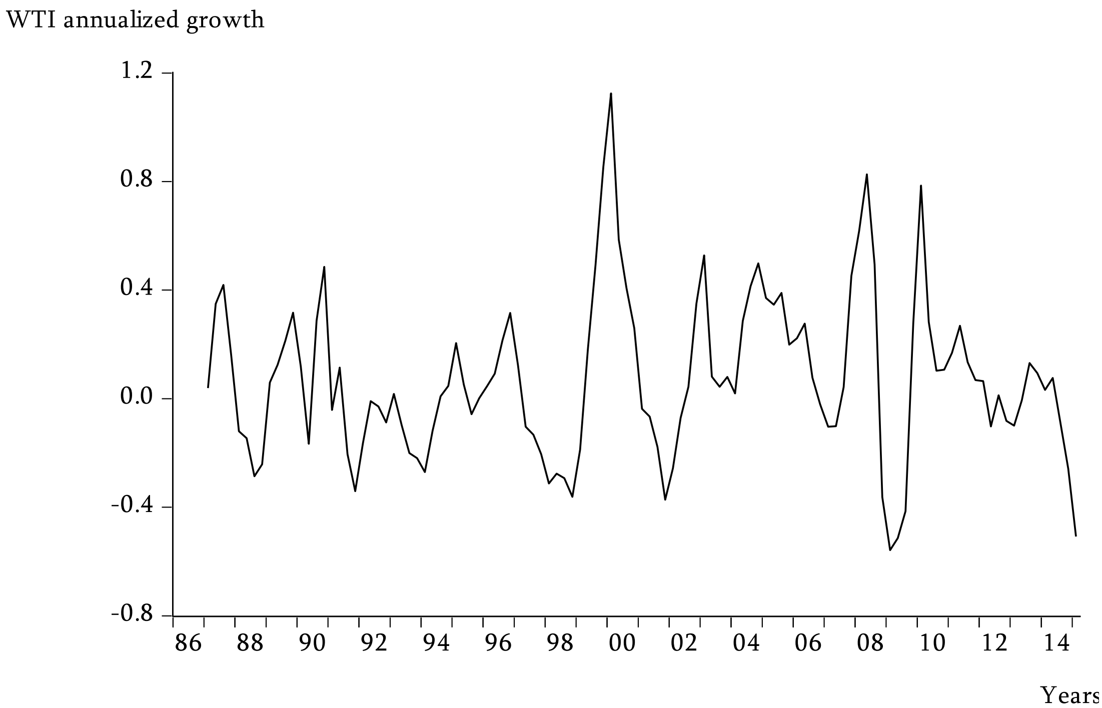

Figure 5. Annualized growth rate of WTI prices

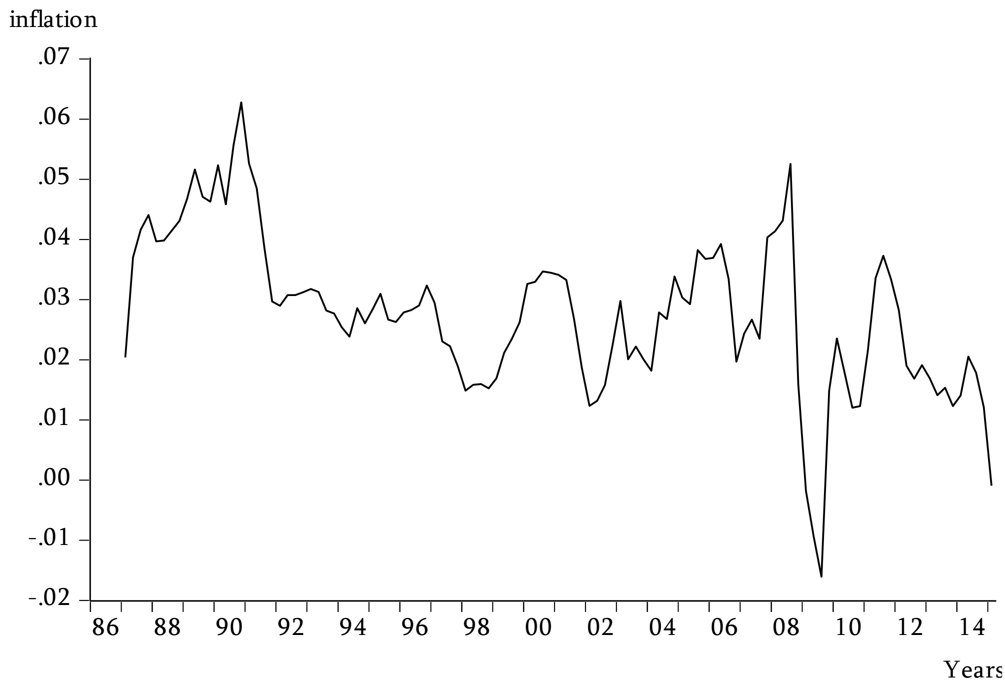

Figure 6. Inflation

In order to confirm whether the series are stationary or not, the same tests are applied. The variables are, again, tested with and without a trend.

Table 4: ADF unit root test

Variables	no-trend	trend
	p-value	p-value
GDP	0.1233	0.0251
WTI	0.0032	0.0207
CPI	0.2099	0.0699

As far as WTI is concerned, the results indicate that it is stationary at first differences and, thus, it has only one unit root. On the other hand, GDP and CPI are stationary only when a trend is including, and more specifically CPI is stationary only at the 10% level of significance.

Table 5: DF-GLS unit root test

Variables	no-trend	trend
	t-Stat.	t-Stat.
GDP	-2.469663	-3.710305
WTI	-3.775598	-3.711326
CPI	2.281369	-2.633410

The DF-GLS test provide similar results. The t-statistic critical value is -1.94 when only a constant is included and -3.02 when a trend is included as well. In both cases examined, GDP and WTI are stationary. However, this is not the case for CPI as when a trend is considered the variable is non-stationary even at the 10% level of significance.

Table 6: PP unit root test

Variables	no-trend	trend
	p-value	p-value
GDP	0.0465	0.1143
WTI	0.0405	0.1614
CPI	0.0693	0.0247

Finally, using the PP unit root test GDP and WTI are stationary when no trend is included, while CPI is stationary only at the 10% level of significance. When a trend is included, CPI becomes stationary at the 5% level of significance, while, on the other hand, GDP and WTI become non-stationary.

After examining the variables with three different tests, it is safe to conclude that the economic growth of US and the oil prices of WTI-Cushing Oklahoma have exactly one unit root and so is CPI but only at the 10% level of significance.

4. Empirical Analysis

4.1. Analysis in the time domain

The first step of empirical analysis consists of examining the presence of a linear causality following the Toda and Yamamoto (1995) approach. The null hypothesis of the test suggests that causality between two variables does not exist. The results of the test are shown in the table 7 below:

Table 7: Wald test

Hypothesis	Probability	Result
WTI doesn’t cause GDP	0.0079	reject
WTI doesn’t cause CPI	0.1398	fail to reject
CPI doesn’t cause GDP	0.0000	reject

Observing table 7 both WTI and CPI have a direct effect on GDP, while WTI fails to Granger-cause CPI. In order to evaluate these results the definition of CPI and GDP must be considered.

The former constitutes the weighted average of prices that consumers pay for goods and services, the so called “basket of goods”. The fact that oil prices do not Granger-cause CPI is troubling, as they have a major impact on the economy of a country. Oil substances are used in most products and services, thus a change in the price of oil should have a direct effect to the value of CPI. However, the analysis followed does not support this theory.

As far as GDP is considered, it reflects the value of goods and services produced in a given period of time. The definition of these two variables is alike and there ought to be a strong direct effect between them. Actually, as already presented at section 2, many articles have proven the existence of this relationship.

Indeed, the results of the Wald test provide the same evidence, that CPI Granger-causes GDP.

Finally, the fact that oil prices affect economic growth is to be expected, as oil is one of the most used good for the production of energy which eventually its price affects the welfare of an economy.

4.2. Analysis in the frequency domain

Switching from the time domain to the frequency domain, the Breitung and Candelon (2006) approach is adopted. The representations received from this analysis are interpreted at the 5% level of significance and presented in the Figures 7, 8 and 9.

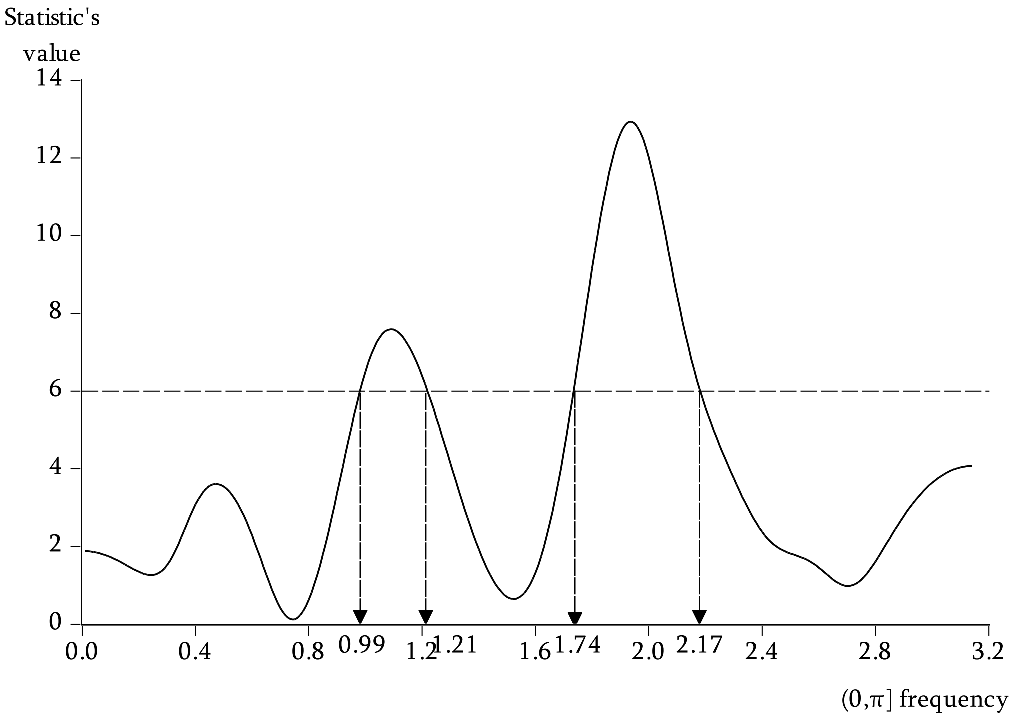

Figure 7. B&C Granger non-causality: CPI from WTI

It is concluded from Figure 7 that crude oil prices can be used to predict how inflation will behave in two different periods. These periods can be found by considering that $\tau = \frac{2*\pi}{\omega}$. As a result, predictability is noticed for wavelengths of more than 2.89 quarters and less than 3.61 quarters ahead, as well as between 5.19 and 6.34 quarters ahead.

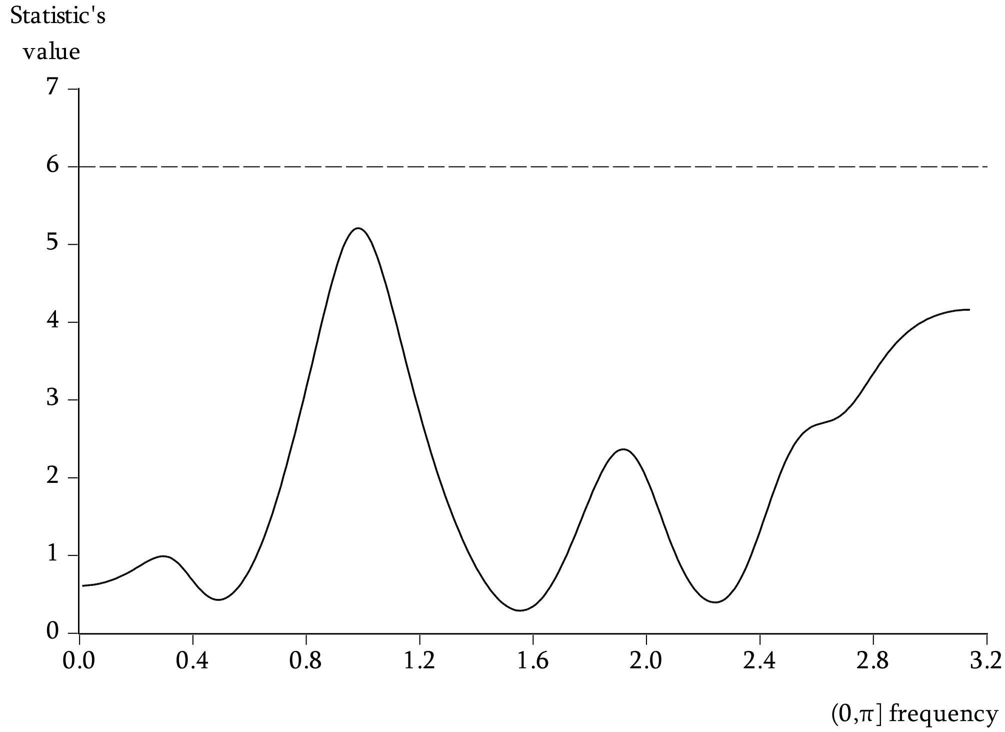

Figure 8. B&C Granger non-causality: GDP from WTI

It is clear from Figure 8 that at the frequency domain there is no predictability of GDP from WTI, whatsoever. These results are expected, as all studies state that since the oil crisis of 1973 the direct effects of crude oil prices in the US economic growth are slowly fading away.

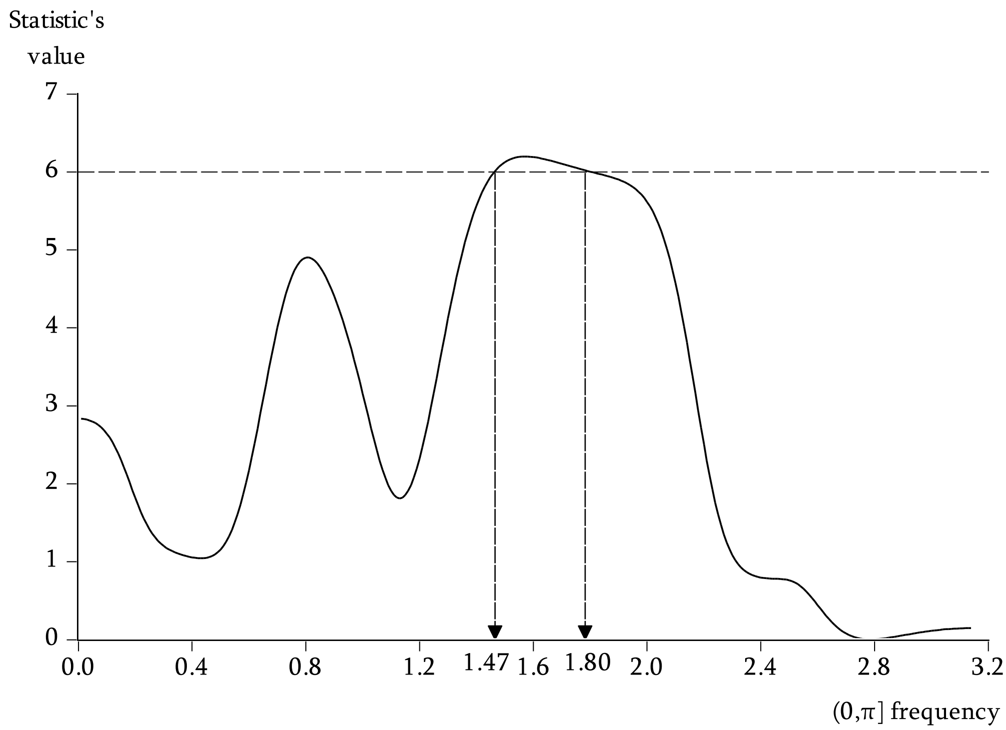

Figure 9. B&C Granger non-causality: GDP from CPI

The last case examined with the B&C method is the relation between inflation and economic growth and the respective results are presented at Figure 9. Although there is predictability from 3.48 up to 4.27 quarters ahead, its significance is slightly above the critical value. Thus, it can be concluded that the causality channels running from inflation to economic growth are unobservable.

To sum up, from the two methods applied definitive conclusions cannot be drawn, as the results are in total confront with each other. However, this is not something that comes as a shock, as the two methods are fundamentally different. The Toda and Yamamoto (1995) method analyzes the significance between the variables in the time domain, while the approach of Breitung and Candelon (2006) examines whether there is any predictability from one variable to another by examining them at the frequency domain.

4.3. Impulse responses

The final step of the empirical analysis consists of imposing an impulse on the causal variables and examining the response of the target variables. The categorization of the variables to causal and target ones is the same with the previous steps. Two types of impulses are used, the common impulse response and the impulse response based on local projections.

The results of the common impulse responses are shown in the Figures 10, 11 and 12 below.

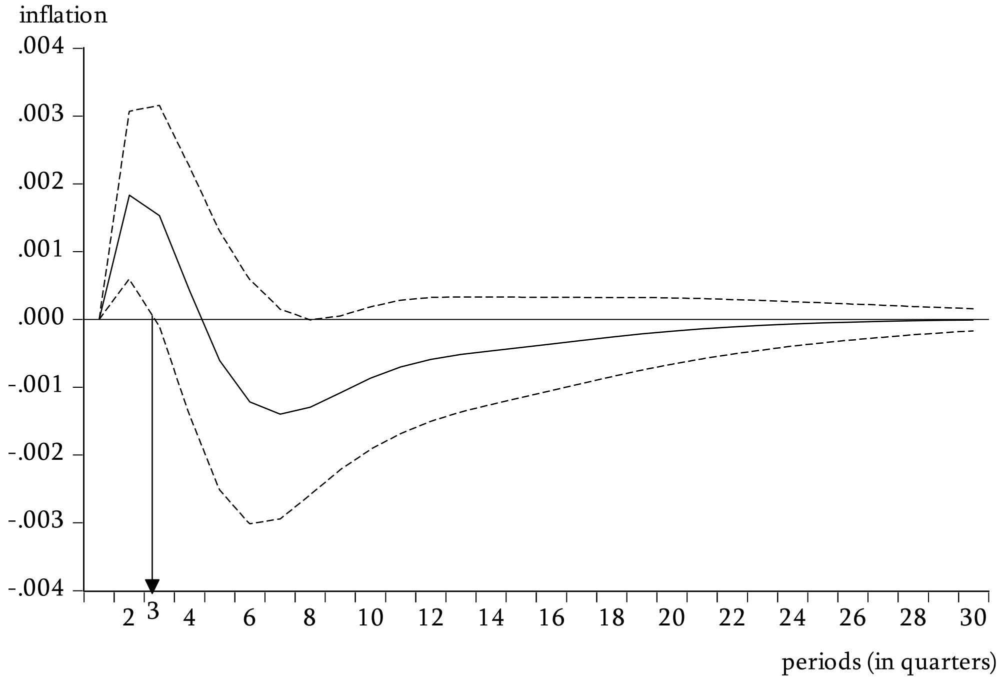

Figure 10. Response of CPI to WTI

An impulse on crude oil prices has until the third period a significant positive impact on inflation (Figure 10). However, after the third period this impact is insignificant and remains as such until it finally fades away. Additionally, it must be noted that around in the fifth period the impact becomes negative.

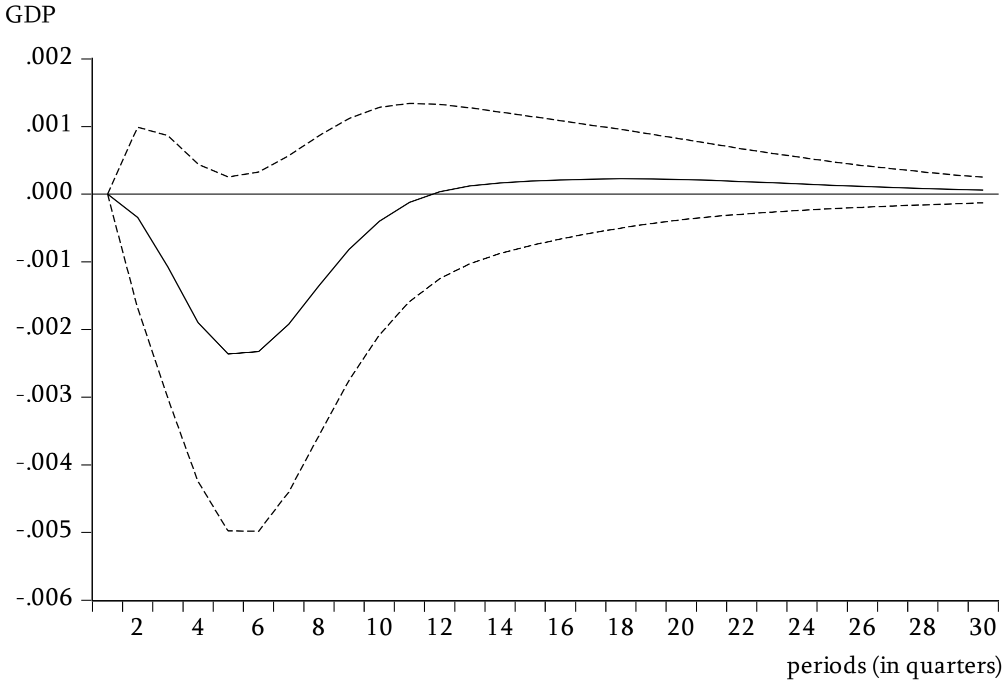

Figure 11. Response of GDP to WTI

Furthermore, an impulse on crude oil prices has throughout the period examined an insignificant impact on economic growth (Figure 11). It should be noted though, that in the first 11 periods, the impact is negative and afterwards it becomes positive until it fades away.

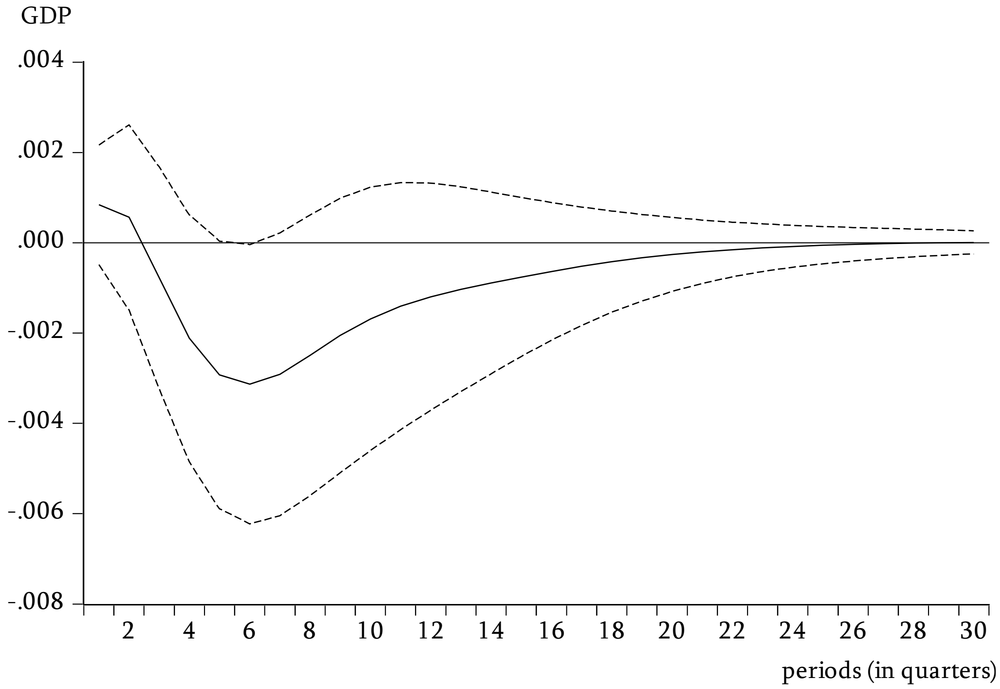

Figure 12. Response of GDP to CPI

In the last case, the response of economic growth to an impulse of inflation is accordingly plotted (Figure 12). In a common manner as in the case of crude oil prices – economic growth the effects are insignificant, while up to the third period the effects are positive and then they become negative.

Proceeding with the examination of the impulse response effects, the results of impulse responses based on local projections are presented at the figures 13, 14 and 15.

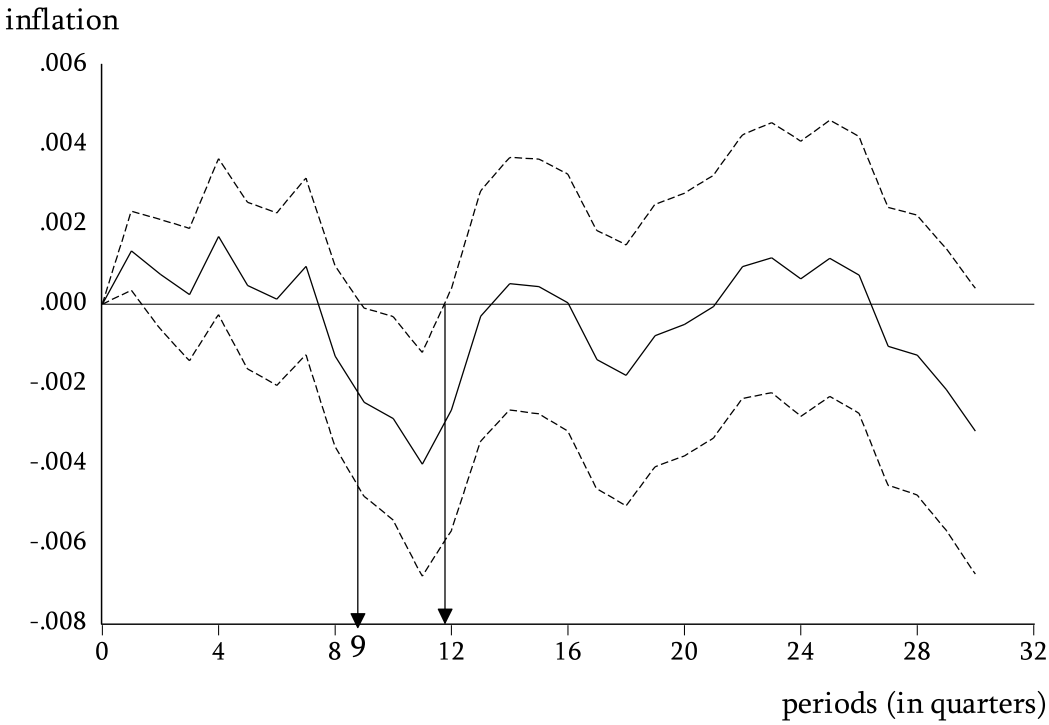

Figure 13. Jorda response of CPI to WTI

A sudden change of crude oil prices will result to a significant impact on the inflation only between 9 and 12 quarters ahead, and that the impact will have a negative effect (Figure 13). This means, that there is a time lag in order to introduce effects of an oil crisis on the inflation of an economy.

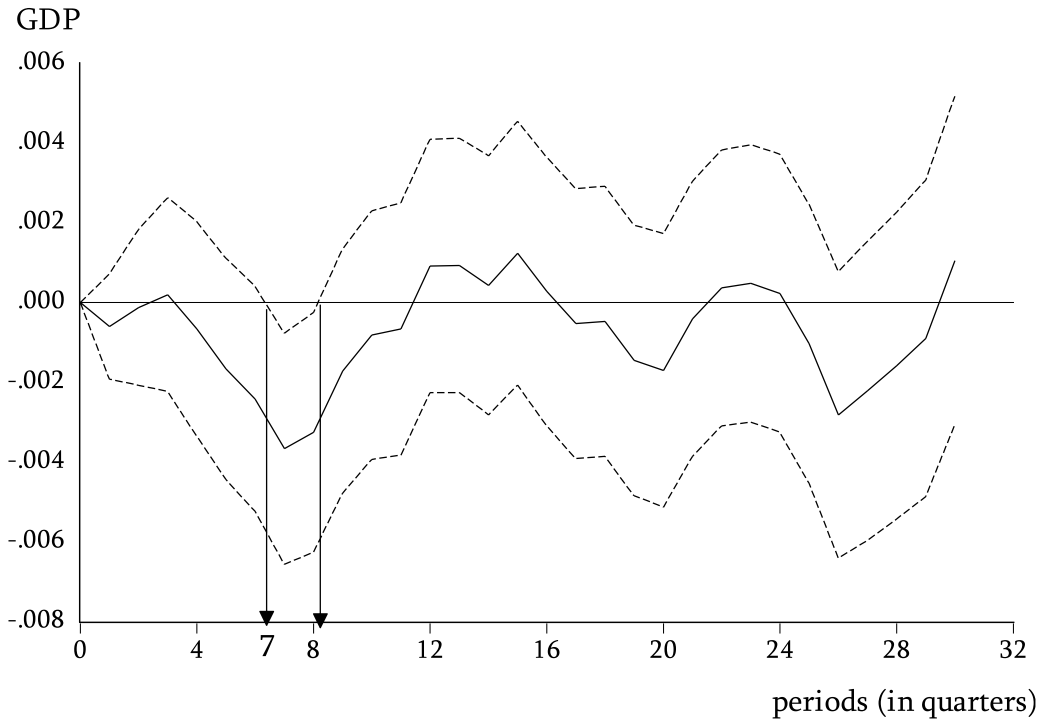

Figure 14. Jorda response of GDP to WTI

The same results can be concluding by observing Figure 14. The impulse response is significant and negative between 7 to 8 quarters ahead and the magnitude of the effect is alike. The duration, however, of the crisis is much less than in the first case, strengthening the opinions that crude oil prices and economic growth have a weakening relationship.

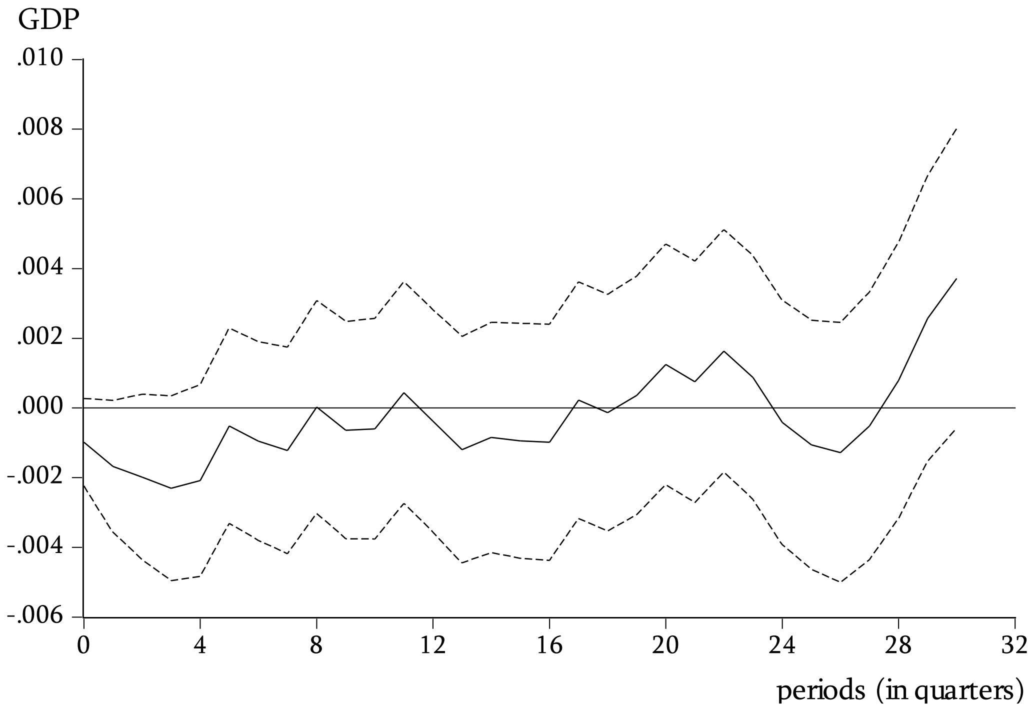

Figure 15. Jorda response of GDP to CPI

The response of GDP to an innovation on CPI is similar with that of the common impulse response and it is presented in Figure 15. The relationship is insignificant for all the periods studied.

As a final step, the responses are plotted (Figures 16, 17 and 18) together in order to compare effectively this two different approaches.

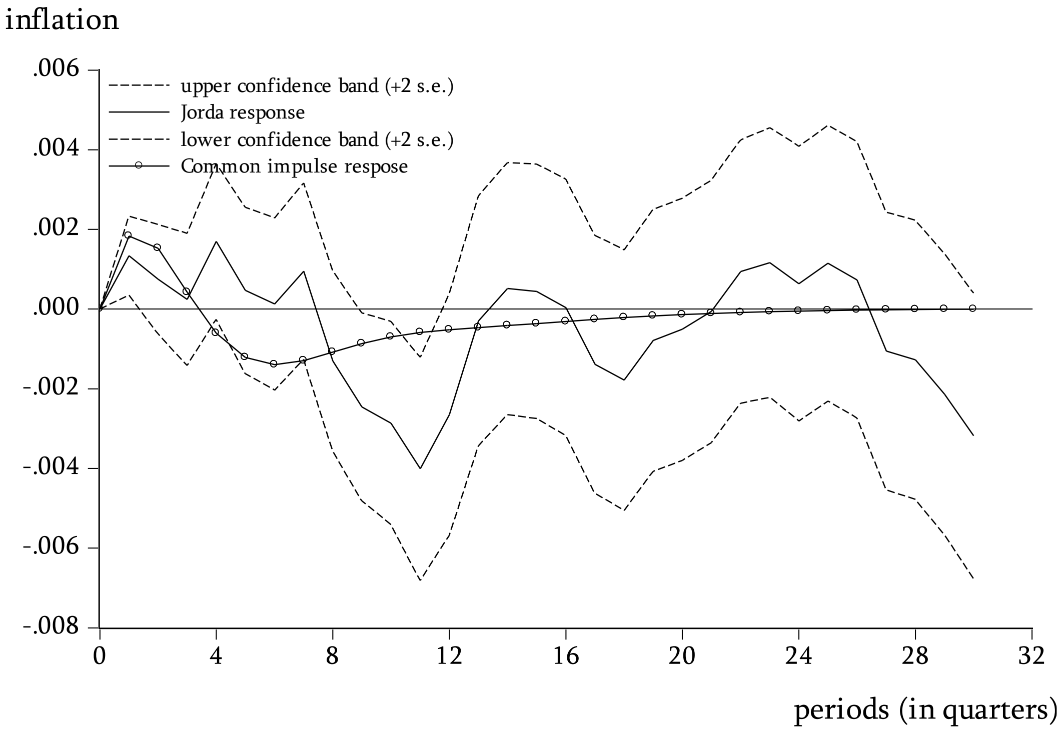

Figure 16. Common figure for the response of CPI to WTI

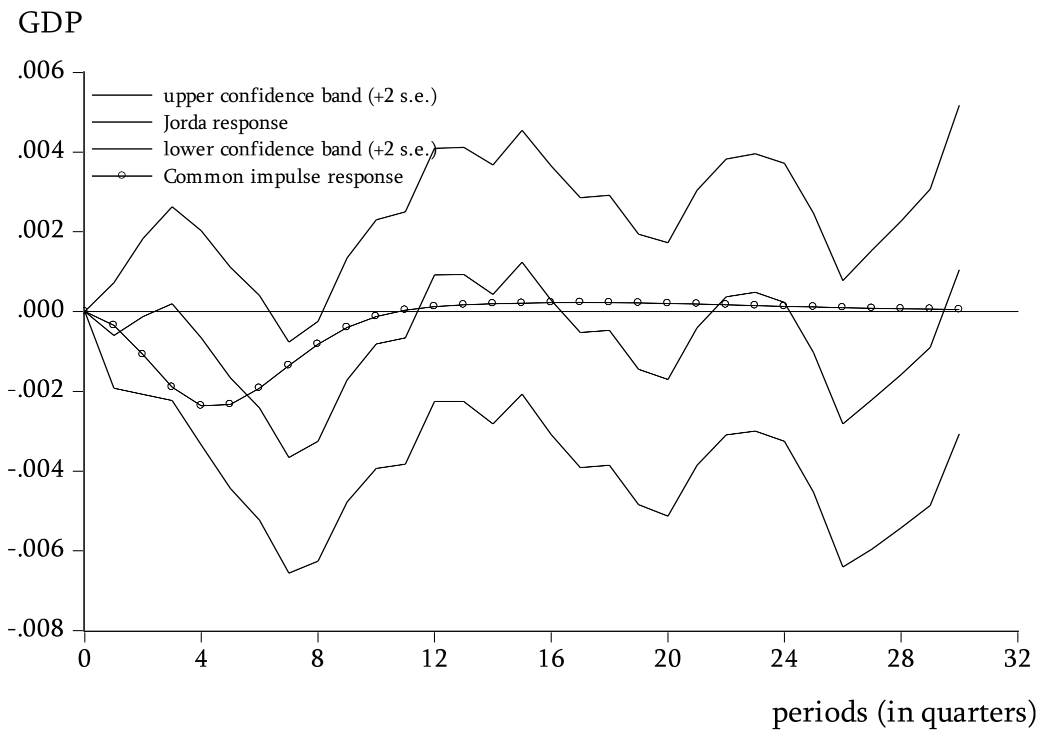

Figure 17. Common figure for the response of GDP to WTI

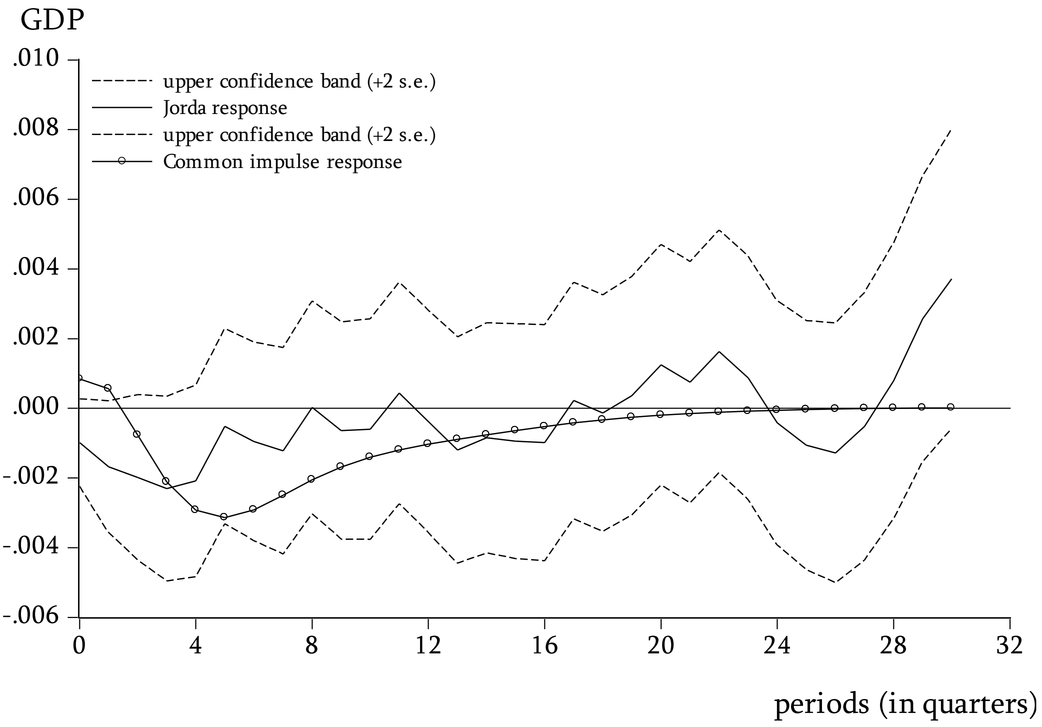

Figure 18. Common figure for the response of GDP to CPI

The main difference between the two methods is that when a significant relationship is observed, the results are immediate in the common impulse response, while in the second one there is a lagged response. However, the latter seems to be more appropriate as changes in macroeconomic variables cannot be transferred to one another in the same time the crisis occurred.

5. Conclusion

The effects of crude oil prices on the macroeconomy of a country is a common subject discussed and investigated by many researchers. More specifically, after the 1973-1974 crisis and its devastating effects on the economy, there have been many studies around the direct and indirect causality between oil prices and macroeconomic variables. Most of the studies, like these of Doroodian and Boyd (2003) and Roeger (2005), suggest that after 1973, due to the monetary policy that countries adopted, the direct effects of oil prices on the economic growth and the inflation have been significantly weakened.

In this study, I examined the relationship between crude oil prices, inflation and economic growth for US in two different ways. Firstly, I analyzed their relationship in the time domain following the Toda and Yamamoto (1995) approach and then I continued in the frequency domain, a method developed by Breitung and Candelon (2006). The former suggests that oil prices have a direct effect on the economic growth of US while, on the other hand, no causality channels running to inflation are identified. As far as inflation is concerned, its fluctuations does influence the development of economic growth. The findings occurred from the second method are completely contradictory. It is indicated that oil prices can be used to predict the movements of inflation. In contrast, there is a rather weak predictability for economic growth and there is no relationship of inflation with economic growth, whatsoever.

To quantify the identified causality channels, common impulse responses as well as impulse responses based on local projections, developed by Jorda (2005), are used. The outcome of these strengthens the already known literature, as even in the cases that a strong causality is identified, the effects are weak. To be more specific with common impulses, significant and positive effects are noticed only in the case of crude oil prices – inflation relation. When the second type of impulses are used, again crude oil prices have a significant impact on inflation, yet this time it is negative. Additionally, oil prices affect economic growth with a negative impact. It is worth noting, though, that these effects are observed almost two years after the initial oil shock having a small duration, especially in the case of economic growth whereby the effects are present for less than a quarter. Finally, both cases present no significant impact of an inflation innovation to the economic growth of US.

To sum up, the findings of this study are in consensus with the rest of the existing literature. Specifically, a relationship between crude oil prices and the macroeconomic variables of economic growth and inflation is present in the US. This relationship is both qualitatively and quantitatively weak, that is the impacts are of small value and for a short period of time. As future work, it would be a step forward to examine the relationship of the variables in chain causality in order to identify whether the indirect impacts of crude oil are still significant for the economy.

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