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Oil Price-Inflation Pass-Through in the United States over 1871 to 2018: A Wavelet Coherency Analysis

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Abstract

This paper analyzes the oil price-inflation pass-through by studying the relationship between oil prices and U.S. Consumer Price Index (CPI) over the period January 1871- June 2018, at different frequencies, using a wavelet coherency analysis. Our main results suggest that the relationship between oil prices and CPI has changed over the analyzed time period, implying a decrease in the oil price- inflation pass-through over time. Furthermore, this relationship also varies across frequencies, suggesting that the evidence of oil price-inflation pass-through with oil prices leading CPI is weaker in the short-run.

Keywords: Oil prices; Consumer Price Index; Pass-through; Wavelet coherency.

JEL classification codes: C49, E31, Q43.

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1. Introduction

Oil prices play a key role in the global economy, through their impact on many economic variables such as inflation rates (Hamilton, 1983, 1988; Mork, 1989; Hooker, 1996), although the strength of this relationship has varied over time. For example, while US Consumer Price Index (CPI) doubled from 41.20 in 1972 to 86.30 in 1980 coinciding with the oil price shocks in the 70s (oil prices increased from $3.5 in 1973 to $38 in 1979), the oil price increase during the Gulf War oil crisis in 1990 was followed by 6% increase in the CPI. Moreover, during the oil price decline in 2014-2016 (the monthly average price of crude oil fell by a nearly 70% between June 2014 and February 2016), CPI slightly decreased from 238.3 in June 2014 to 237.1 in February 2016. In a context of high volatility in oil prices, the analysis of the relationship between oil prices and inflation rate, the oil price-inflation pass through, has important implications for the implementation of monetary policies since monetary authorities design their policies to keep future inflation under control (Bernanke et al., 1997, 2004; Hamilton and Herrera, 2004; Chen, 2009; Kormilitsina, 2011).

From a theoretical point of view, different channels of transmission are behind the oil price inflation pass-through, or the relationship between oil prices and CPI (European Central Bank, 2010; Alvarez et al., 2011, 2017). First, changes in oil prices will result in an increase of the prices of oil derivatives consumed by households, such as vehicle and heating fuel. Second, oil and derivatives are used as an additional input in different production processes, so that an increase in oil prices will suppose an increase in the cost of the output of these processes. In this case, the intensity or the strength of the oil price-inflation pass-through will depend on the oil dependence of the economy (Hamilton, 1996; Hooker, 2002; De Gregorio, 2007). Furthermore, changes in oil prices might impact, through their effects on economic policy uncertainty (Kang and Ratti, 2013) and inflation expectations, on the determination of wages, and thus, on inflation rates, implying that the oil price-inflation will depend on the effectiveness of the monetary policy influencing those inflation expectations (Hooker, 2002; De Gregorio, 2007; Herrera and

Pesavento, 2009) or more flexible labor markets (Blanchard and Galí, 2007; Clark and Terry, 2010). Moreover, as pointed out by Baumeister and Kilian (2014), the CPI could also affect oil prices, since an increase in food prices, for example, could cause an increase in agricultural activity which would lead to higher demand for farm machinery, and thus, a higher demand for oil, so that, according to these authors, the evidence of oil price-inflation pass through would be weak. In addition, higher inflation is likely to cause monetary authorities to respond via increases in interest rate, resulting in contraction of the economy, and hence, lower demand for oil. This in turn, would reduce oil prices. Hence, while oil prices are likely to increase CPI, the effect of CPI on oil prices could either be positive or negative.

An extensive number of empirical papers on the relationship between oil prices and CPI can be found in the literature (Hooker, 2002; Cunado et al., 2003, 2015; Blanchard and Galí, 2007; De Gregorio et al., 2007; Habermeier et al., 2009; Clark and Terry, 2010; Choi et al., 2017). Hooker (2002), for example, tests for structural breaks and non-linearities in different specifications of the Phillips curves and finds that oil price shocks contributed substantially to core inflation until 1981, while since that time the pass-through has declined sharply, primarily due to the decrease in the oil share in the U.S. economy and to the change in the monetary policy, which remained less responsive to oil price shocks. Blanchard and Galí (2007) estimate the effect of an oil price shock using the structural Vector Autoregression (VAR) techniques and also find that the impact of an oil price change has substantially changed over time. De Gregorio et al. (2007) also report evidence of a significant decline in the pass-through from the oil price to the general price level by testing for structural breaks in augmented Phillips curve specifications, and by estimating rolling VAR models. Clark and Terry (2012) use Bayesian methodology to estimate a VAR model with time-varying parameters and stochastic volatility. They also find evidence of a reduction in the pass-through of oil price to inflation rates. Chen (2009) analyses the oil price pass-through into inflation by estimating a time-varying pass-through coefficient using data for 19 countries and find a decline effect of oil shocks on inflation rates. Choi et al.

(2017) study the impact of oil prices on inflation using a panel of 72 countries over the period 1970-2015 and find that, on average, a 10% increase in oil prices is followed by a 0.4% impact on domestic inflation. Furthermore, they also find that the impact of oil prices has declined over time.

The literature also points out that the underlying forces behind the oil price increases will determine the impact on economic activity and inflation rates (Kilian, 2009; Kilian and Park, 2009). According to Kilian (2009), while an oil supply disruption will have little effect on the price level of the economy, a positive oil demand shock will raise consumer prices. Assuming that recent oil price changes are oil supply disruptions, this result could also explain the empirically observed decline in the oil price pass-through into inflation.

In this context, the objective of the paper is to analyze the strength of the oil price-inflation pass-through, or the relationship between oil prices and U.S. CPI over a long-span time period (January 1871-June 2018) and at different frequencies. The main contributions of the paper are the following. First, while most of the empirical studies using VAR-type models to estimate the relationship between these two variables, the wavelet coherency methodology used in this paper allows us to determine how the relationship between these two variables evolve through time and frequency. Wavelet coherency evaluates how causalities between oil price changes and inflation rates fluctuate across frequencies and vary over time. This allows us to obtain both the short-term (high frequency) as well as the long-term (low frequency) relationships between the two underlying series, and thus controls for potential nonlinearities and structural breaks in the relationship between these variables. Second, the analysis covers the longest possible historical time period from January 1871 to June 2018, a period in which both oil price changes and inflation rates have evolved heterogeneously over time, which suggests that the strength and sign of the relationship between the two variables might have changed over the analyzed period. Third, with a robustness purpose, interest rates and a dummy variable for the recession have also been included in the model in order to take into account the impact of these

variables on the relationship between oil prices and the CPI. To the best of our knowledge, this is the first paper to conduct a historical analysis of the relationship between oil and consumer prices in the US using a time-varying approach across frequencies, i.e., based on wavelet.

Our main results suggest that the relationship between oil prices and CPI has changed over the analyzed time period, implying a decrease in the oil price- inflation pass-through over time. Furthermore, this relationship also varies across frequencies, implying that the evidence of oil price-inflation pass-through with oil prices leading CPI is weaker in the long-run (low frequency).

The remainder of the paper is structured as follows. Section 2 describes the methodology. Section 3 presents the data and the main empirical results, while Section 4 contains some concluding comments and policy implications.

2. Methodology

Wavelet coherency is an effective econometric tool for providing a fresh look into the cyclical (or anti-cyclical) and lead-lag relationships between two variables (CPI and Oil price (OP) under consideration in this study) by allowing us to effectively depict it under different and well-specified time periods and across frequencies. The Wavelet coherency enables us to determine the cross-correlation between the two variables under consideration as a function of time and frequency. Given the two time-series CPI and Oil price, the wavelet coherency ($Q_n^2(s)$) can be expressed as follows:

$$Q_n^2(s) = \frac{S(s^{-1}W_n^{CPI,OP}(s))}{S(s^{-1}|W_n^{CPI}(s)|^2)\times S(s^{-1}|W_n^{OP}(s)|^2)} \quad (1)$$

where S is the smoothing operator, i.e. the traditional correlation coefficient used to calculate the Wavelet Coherence as a localized correlation coefficient following the time-frequency space. Hence, equation 1 may be expressed in polar form as follows

$$Q_n^2(s) = |Q_n^2(s)|e^{i\varphi_{CPI,OP}} \quad (2)$$

The absolute value of the complex wavelet coherence of two time series is named the wavelet coherency ($R_n^2(s)$) and is denoted by:

$$R_n^2(s) = \frac{\left|S\left(s^{-1}W_n^{CPI,OP}(s)\right)\right|^2}{S(s^{-1}|W_n^{CPI}(s)|^2)\times S(s^{-1}|W_n^{OP}(s)|^2)} \tag{3}$$

Now in order to remove the impact of the interest rate and the crisis we used partial wavelet coherency, an approach proposed by Aguiar-Conraria and Soares (2011) which can be defined as follows

$$R_n^2(s)_{CPI,OP|Z} = \frac{|(\mathfrak{T}_{OP,CPI}^n)|^2}{(\mathfrak{T}_{CPI,CPI}^n)\times(\mathfrak{T}_{OP,OP}^n)} \tag{4}$$

where: $\mathfrak{T}_{OP,CPI}^d$, $\mathfrak{T}_{CPI,CPI}^d$, and $\mathfrak{T}_{OP,OP}^d$ are the minors associated with the smoothed cross wavelet transforms $|S(s^{-1}W_n^{CPI,OP}(s))|^2$, $|S(s^{-1}|W_n^{CPI}(s)|^2)|$ and $|S(s^{-1}|W_n^{OP}(s)|^2)|$ respectively in a 3×3 matrix $\mathfrak{T}$ and Z is a matrix of additional control variables whose influence will be removed from the estimated coherency between CPI and Oil prices.

We used 1000 replications in the Monte Carlo methods in order to find the critical values for the wavelet coherence at the 5% level of significance. These critical values are used in order to determine the confidence interval of the phase difference or the phase relation between two time series. Based on equation 2, the angle ($\varphi_{CPI,OP} = \varphi_{CPI} - \varphi_{OP}$) is called the phase difference. The main advantage of the phase difference is the fact that it cannot be affected by the smoothing choice (Aguiar-Conraria and Soares, 2011). The phase difference and partial phase difference may be written as follows in Eq.5 and Eq.6 respectively:

$$\varphi_{CPI,OP} = tan^{-1}\frac{I\{W_n^{CPI,OP}\}}{R\{W_n^{CPI,OP}\}}, \quad \varphi_{CPI,OP} \in [-\pi,\pi] \tag{5}$$

$$\varphi_{CPI,OP|Z} = tan^{-1}\frac{I\{W_n^{CPI,OP|Z}\}}{R\{W_n^{CPI,OP|Z}\}}, \quad \varphi_{CPI,OP|Z} \in [-\pi,\pi] \tag{6}$$

The imaginary and real parts are indicated by I and R, respectively, of the smooth power spectrum. The phase relationship between the two time series is characterized using the underlying path difference, which is considered useful. The time series moves together with a

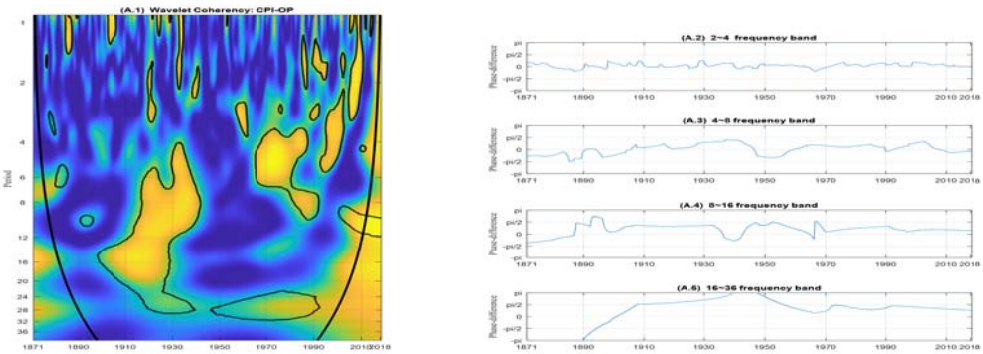
specified frequency if phase-difference values range to zero. The series move in phase if $\varphi_{CPI,OP} \in [0, \pi/2]$ when the series CPI is led by Oil price. In contrast, if $\varphi_{CPI,OP} \in [-\pi/2, 0]$, then CPI is leading Oil price. Furthermore, an anti-phase relation (analogous to negative covariance) is found if $\varphi_{CPI,OP} \in [\pi/2, \pi]$; then, CPI is leading over Oil prices, and Oil prices are leading over CPI if $\varphi_{CPI,OP} \in [-\pi, -\pi/2]$. Throughout the rest of this study, we gauge empirically the nexus of Oil prices and the CPI. The same holds true in the case of the phase–difference obtained from the partial coherency analysis.

3. Data and Results

The data on West Texas Intermediate (WTI) oil price is derived from the Global Financial Database, while CPI data is obtained from the data segment of the website of Professor Robert J. Shiller.[1] We take natural logarithms of both these variables. Our sample covers the monthly period of January, 1871 to June, 2018, with the start and end date being driven by data availability at the time of writing this paper.

We first present the co-movements between the CPI and international oil prices, using the wavelet coherency (Fig. 1).

Fig. 1. Wavelet coherency between the CPI and international oil prices



Note: Wavelet Coherency between CPI and oil prices. The black contour designates the 5% significance level estimated from the Monte Carlo simulations based on an ARMA(1,1) Null. The color code for power ranges from blue (low power) to yellow (high power). If phase difference lies between $[0, \pi/2]$*, then the series are in-phase, with the time-series oil prices leading CPI. On the other hand, if*

[1] The data is available for download from: http://www.econ.yale.edu/~shiller/data.htm.

phase difference lies $[-\pi/2,0]$ *then CIP is leading. If we find evidence that phase-difference lies between* $[\pi/2,\pi]$ *then CPI is leading, and the time series oil prices is leading if phase difference lies between* $[-\pi,-\pi/2]$ *whiles both series have an anti-phase relationship.*

As evident from Fig.1 that below 2 years of scale there are very small areas where coherency is significant. Hence, we do not concentrate on this frequency while analyzing the phase-difference. Now if we look at the 2-4 years scale, we find significant evidence of coherency around 1920, 1940, 1960, 1968-1985, and 1995-2010 and in all these years the phase-difference is between $[0,\frac{\pi}{2}]$, indicating that both series are in-phase and the oil prices are leading the CPI.

Next when we look at 4-8 years scale band, we find that significant area of coherency corresponds to 1915-1940, 1965-1985, and 1995-2000 and in all these periods, as found above, the phase-difference were between $[0,\frac{\pi}{2}]$, indicating that both series are in-phase and the oil prices are leading the CPI.

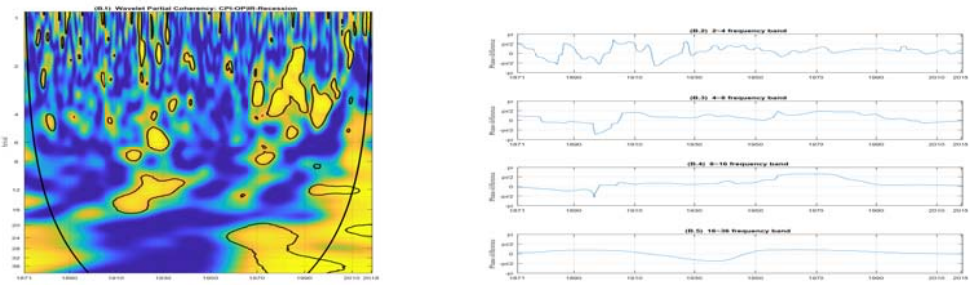
Next when we look at 8-16 years scale band, we find that significant area of coherency corresponds to 1900-1940, 1980-1995 and 2000-2010. The evidence from phase-difference show that the phase-difference is between $[\frac{\pi}{2},\pi]$ around 1995, indicating that both series have anti-phase relationship and the CPI is leading. Further evidence shows that around 1940 phase difference was between $[-\frac{\pi}{2},0]$, implying that both series move in phase and CPI is leading and in all other years phase-difference was between $[0,\frac{\pi}{2}]$, suggesting that both series are in-phase and the oil prices are leading the CPI.

Finally, we observe that at 16-36 years scale band, significant area of coherency corresponds to 1900-1940, and 1945-1992 and the phase-difference around 1900-1905 is between$[0,\frac{\pi}{2}]$, indicating that both series are in-phase and the oil prices are leading the CPI. Further evidence show that during 1900-1960 the phase-difference was between $[\frac{\pi}{2},\pi]$, and hence both series have anti-phase relationship and the CPI is leading. For all other periods i.e.

during 1965-1992 the phase-difference were between $[0, \frac{\pi}{2}]$, suggesting that both series are in-phase and the oil prices are leading the CPI.

Nevertheless, these results can be subjective because of omitted variables bias. Hence, to overcome this problem we included the impact of the interest rate and we also added a dummy variable for the recession and then partial coherency is re-calculated. The short-term interest rate data is obtained from the website of Amit Goyal,[2] while the recession dates are derived from the National Bureau of Economic Research (NBER).[3] Results of partial coherency and phase-difference derived from the partial coherency are presented in Figure 2.

Fig. 2. Wavelet partial coherency between the CPI and international oil prices



Note: Wavelet Coherency between CPI and oil prices. The black contour designates the 5% significance level estimated from the Monte Carlo simulations based on an ARMA(1,1) Null. The color code for power ranges from blue (low power) to red (high power). If phase difference is lies between $[0, \pi / 2]$*, then the series are in-phase, with the time-series oil prices leading CPI. On the other hand, if phase difference lies* $[-\pi / 2, 0]$ *then CPI is leading. If we find evidence that phase-difference lies between* $[\pi / 2, \pi]$ *then CPI is leading, and the time series oil prices is leading if phase difference lies between* $[-\pi, -\pi / 2]$ *whiles both series have an anti-phase relationship.*

Our first observation shows that in 2-4 years scale band phase difference have more fluctuations as compared to the previous case when the influence of interest rate as well as the recession were not removed and for all other scales phase difference becomes much stable.

First, short-run co-movements observed at 2-4 years cycle show that across period phase-difference falls between $[0, \frac{\pi}{2}]$, indicating that both series are in-phase and the oil prices are

[2] The data is downloadable from: http://www.hec.unil.ch/agoyal/.
[3] The recession dates are available at: http://www.nber.org/cycles.html.

leading the CPI. Same results for phase-difference are observed at 4-8 years scale with only exception to 1980 when phase difference were between $[-\frac{\pi}{2}, 0]$ indicating that both series move in phase and CPI is leading. For all other higher scales too, i.e., at 8-16 years scale and 16-36 years scale, phase difference in all significant areas of coherency were between $[0, \frac{\pi}{2}]$, indicating that both series are in-phase and the oil prices are leading the CPI.

In general, irrespective of whether we control for recessions and the interest rate effects or not, our results tend to suggest that causality primarily runs from oil prices to the CPI and with a positive sign, and when indeed there is a feedback from the CPI to oil prices, the sign is negative primarily. This latter result tend to indicate that higher inflation results in higher interest rate and hence, contraction of the economy and falling oil prices with oil demand contraction.

4. Conclusions

This paper analyzes the oil price-inflation pass-through by studying the relationship between oil prices and U.S. Consumer Price Index (CPI) over the period January 1871- June 2018, at different frequencies, using a wavelet coherency analysis. Wavelet coherency evaluates how causalities between oil price changes and inflation rates fluctuate across frequencies and vary over time. The main results are the following.

First, we find that, for all frequencies, the relationship between oil prices and the U.S. CPI has changed over the analyzed period, suggesting, as already found in the literature, a decrease in the oil price-inflation pass-through over time. Furthermore, our main contribution is to show that the strength of the relationship between these two variables depends on the frequency, suggesting that there is more evidence of oil prices-inflation pass through in the medium and long-runs (4-8 years, 8-16 years and 16-36 years scale), than in the short run (2-4 years scale). Moreover, the decrease in the oil prices-inflation pass through over time is more evident for the short-run. Finally, when, for robustness purposes, the interest rates and a dummy to control for

recession are included in the analysis, the main conclusions on the oil prices and the CPI relationship remain valid.

Policy implications for monetary authorities could be drawn from the results. As already mentioned in the literature, the lower oil price- inflation pass-through observed in the more recent period could be due to the more credible monetary policy. Furthermore, policy authorities should also take into account that although the impact of oil prices on the CPI is significant in the medium and long-runs, the strength of this relationship is lower in the short-run. Given the fact that that the US market is the largest one, its policy implications has also important repercussions for other countries. Furthermore, the results from this paper could also be useful to international investors for the reason that both oil and inflation are crucial factors in financial risk management. Since the increasing interaction between international markets this issue seems to become even more pertinent with time.

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