Energy commodities price dynamics:understanding oil price volatility

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Sommario

This paper aims to explain crude oil price volatility and its relationship respect to some macroeconomic and financial variables. Finding the main drivers of oil price dynamics is a crucial element for the definition of adequate monetary policies and risk management purposes. The role of macroeconomic and financial variables is analyzed in a Vector Error Correction Model (VECM) framework, in order to test the existence of a long run equilibrium in the oil price dynamics. We use monthly data for crude oil prices, the Dollar/Euro exchange rate, the US interest rate, the crude oil Futures open interest, the US oil imports and the gold price over the period 1993-2009. One cointegrating relationship is found which allows to identify a long run equilibrium between the variables.

Key words: Crude oil price, gold price, cointegration, vector error correction model.
JEL classification: C32, Q40.

1 Introduction

Analysis and empirical evidence show how four of the last five global recessions were preceded by oil shocks. In the case of the 2007-2008 crisis, oil prices cannot be ignored as culprit of what happened: oil prices increased of over 300% and this has caused the annual fuel bill of OECD countries to increase enormously (Rubin (2009), Hamilton (2009a and 2009b), Roubini (2009)). The high price of oil in July 2008, at $145 per barrel, was caused by strong demand confronting stagnating world production and it was the primary reason for US, Japan and Eurozone to enter into a recession.

The exceptional oil price volatility has affected many other economic variables and their related markets. Oil price fluctuations affect consumers, producers and marketers especially in terms of costs, incentives to invest in technology and trading strategies. The importance of oil prices may also be increased by the fact that other forms of energy (coal, gas, and, to a lesser extent, electricity) are sometimes priced in order to compete with oil, so that oil price fluctuations become reflected in broader energy price changes, Bencivenga et al. (2011).

Some economists (i.e., Krugman (2008)) sustain that the "oil bubble" is not due to speculation but it may be a result of other variables linked to the growing consumption of emerging countries (i.e., China, India) and the increasing cost of exploration and drilling activities. Other financial experts believe (Soros (2008)) speculators have also been responsible for driving crude oil prices to their peaks in the first half of 2008. Basically trend-following speculation and institutional commodity-index-buying reinforced the output pressure on prices.

The debate is still on, certainly oil price changes cannot be explained solely looking at supply and demand dynamics. The aim of this paper is therefore to identify which economic and financial variables provide insights to understand oil price dynamics. Our idea is that oil prices are an example of an economic variable which is completely unpredictable and recently experienced dramatic price variations over short periods, which had large consequences for oil producers, consumers and policymakers. In such a context, a simple econometric model is unable to capture the nature of the short term volatility, so we choose a VECM framework to capture a possible long run equilibrium, if it exists.

Using monthly data over the period 1993-2009, we examine the relationship among West Texas Intermediate (WTI) crude oil spot and a set of macro-economic and financial variables, which in our opinion are the main drivers of the oil price fluctuations. The chosen variables are the Dollar/Euro exchange rates, gold prices, US interest rates, US oil imports and oil futures open interests. We test the existence of a unique cointegration relationship among these variables.

The remainder of the paper is organized as follows. Section **??** provides an overview of the recent literature, Section 3 describes the methodology and the data set. In Section 4 the empirical results are reported. Section 5 draws some conclusions.

2 Recent Literature

The related literature on the determinants of oil prices is very extended. We concentrate on recent empirical studies which try to explain and measure oil prices increases as function of economic and financial variables. The crude oil prices volatility and its role in the financial crisis is investigated by Hamilton (2009a, 2009b) trying to consider the role of the economic theory predictions, versus the role of the macroeconomic fundamentals. He explores three broad ways: the first based on statistical regularities of prices, the second based on economic theory predictions and the third examining the fundamental determinants - demand and supply behavior. He finds that the three key features are the low price elasticity of demand, the strong growth in demand from emerging countries and the failure of global production to increase. These three elements explain the initial strong pressure on prices which may have triggered commodity speculation.

A key macroeconomic variable is certainly represented by the exchange rate. The impact of exchange rates on commodities and vice versa has been largely investigated (i.e, see Chen et al. (2008)). Some authors highlight the role of the dollar as numéraire (see Geman (2005), Cuaresma and Breitenfellner (2008)) of standard commodities since a change in dollar exchange rate inevitably modifies the terms of trade among each couple of countries (i.e., see Schulmeister (2000)). In a flexible exchange rate market, changes in commodity prices are affected by their numéraire. Several studies have exploited exclusively the relationship between exchange rates and oil prices. In most cases oil prices has been treated as an exogenous variable, which explains exchange rate fluctuations, Amano and Norden (1998a and 1998b). Cuaresma and Breitenfellner (2008) perform a simple forecasting exercise using a vector correction model (VECM), in order to evaluate whether changes in dollar/euro exchange rate contain information about future changes in oil prices. They show that exchange rate data helps oil price forecasting. Chen and Chen (2007) assess the role of real oil prices in predicting real exchange rates over long horizons, they focus on the long-horizon forecasting power of real oil prices to explain movements in real exchange rates.

The physical (non financial) determinants of the real price of Brent crude oil are investigated in Chevillon and Rifflart (2007) using an ECM framework over the last two decades. They examine, as exogenous variables, the demand for oil from the OECD [1] together with non-OECD (especially China and India) demand and inventories. The frequency of data is quarterly and the data set refers to the period 1989-2005. They find two cointegrating relations affecting oil price changes. The first refers to OPEC's cartel behavior using its market power and quotas, the second is represented by the coverage rate of expected future demand by OECD using inventories behavior.

In the last decade also the role played by financial investors in the oil market has to be taken into account. Crude oil started to be used as a financial asset in the spot and derivative market for hedging and investment purposes. The use of derivative instruments in commodity market (i.e., oil, gold and other raw materials) have led the oil spot price to rise far above the marginal cost of production (usually defined as equilibrium price), so futures contracts have become crucial. Futures contracts on crude oil was first introduced on the New York Mercantile Exchange in 1983 and in 1988 they were also launched on the London Exchange (IPE). Recently the use of Futures contracts reported a huge growth, in 2003 the daily average volume was 440,000 and increased to 1.9 million in 2009. We should notice that in the oil Futures market the composition of traders recently changed: commercial traders (considered as the traditional traders) represents today the 55% of the market compared to the 75% in 2003, speculators moved from 15% to 40%. This change in the composition of traders made economists to believe that financial markets were the ones who drove the oil prices up. This is not supported by empirical data, especially if we look at the oil price dynamics after 2008: after July 2008 oil prices went to its minimum on January 2009 ($38.7/bd) and this price decline was not followed by a reduction of trading in Futures markets. Actually futures market trading provides very

[1] According to the International Energy Agency (EIA) the OECD countries still represent 60% of the world energy consumption.

useful information on the price trend behavior and is able to highlight the weakness/strenght of the market.

Relationship among the US real price of crude oil and factors which affect its movements over time (futures prices, the value of dollar, exploration, world demand and supply) is examined in Stevans and Sessions (2008), using monthly data from January 1998 to March 2008. The authors include shorter term futures contracts and find that the spot oil prices are dominated by real supply, whereas for longer term contracts the crude oil price is dominated mainly by futures prices. From a policy perspective their conclusions show that if regulators really want to avoid speculation in the oil market they should limit the longer term futures contracts.

Links between spot and futures (for both near and far month maturities) oil prices are investigated in Kaufmann and Ullman (2009). They examine the causal relationship between prices of the different crude oil blends from North America, Europe, Africa and Middle East using a VAR framework. Different data set are used averaging daily observations to weekly values. Their results suggest that the recent rise in oil prices is generated by both changes in market fundamentals and speculation. The increasing demand of non-OPEC countries (i.e. emerging countries) affects the supply/demand balance requiring higher prices. Hence these changes in fundamentals are recognized by speculators who take position accordingly. Increases of prices are anticipated on the futures market and then are transmitted to the spot market, which drives prices beyond levels justified by the existing supply/demand balance.

Recently some authors have investigated the role played by gold, considered another crucial commodity affecting the economy. Although the role of oil and gold is very important in driving price changes worldwide, most of the literature has considered these two commodities independently one from the other. The "gold" investment keeps its value well and can be used to hedge against inflation. Wang et al. (2010) use gold and oil prices to explain economic trend and the stock market behavior in various countries. Diba and Grossman (1984) find a close correspondence between the price of gold and real interest rate so that the latter can be considered as a proxy for the fundamental component of the relative price of gold.

We may argue that oil and gold prices have similar long-term trends because they have one important long-term driver in common: monetary inflation. Oil prices have exploded in 2008 while gold prices have shown marked steady appreciation since 2005. The price of oil was about $ 23/bd and the price of gold approximated $ 272/oz in 2001. In the following seven years both prices have more than tripled : gold has gone over $ 1,000 and the price of oil to more than $60/bd . Looking at the correlation between the two commodity prices a direct strong relationship may be detected. From the 1980, in terms of 2008 dollars, oil prices rose from around $20 USD per barrel to more than $100 USD per barrel . Gold followed along, duplicating between the 80s and 2005 the price and increasing even more in the last five years, Malliaris and Malliaris (2009) analyze the relationship between gold, oil and the euro using a standard time series methodology and in addition employing neural network. The time series analysis demonstrates that both a short term and long term relationship between the three commodities exists. The neural network approach confirms the same result with additional insights. The two approaches allow to identify different level of influence of gold and euro on

Tabella 1
Descriptive statistics.

	WTI_t	r_t	FX_t	Im_t	OI_t	G_t
Mean	48.00	4.07	1.17	$291,247.2$	$209,690.3$	500.7
Median	39.09	4.12	1.20	$292,751.0$	$202,070.0$	410.9
Std. Dev.	26.25	1.21	0.19	22,111.0	79,134.9	242.04
skewness	1.15	0.12	0.02	-0.47	0.45	0.87
Kurtosis	4.06	2.40	2.01	2.53	2.01	2.47

oil prices.

3 The methodology

We aim to identify a long run equilibrium between oil prices and a set of selected key variables which may help to understand the high volatility experienced in the last decades. We select a set of macroeconomic and financial variables which may provide useful insights for the analysis.

3.1 The dataset

The period 1993-2009 is chosen in order to take into account the occurrence of major political and economic changes in the world market:

- a sustained period of US economy expansion (until mid-2000);
- the introduction of the Euro in 1999;
- the terrorist attack to the Twin Towers in 2001;
- the increasing role of the emerging economies (BRIC);
- the financial crisis in 2008.

The time interval would allow to capture possible structural breaks or meaningful changes in the dynamics of the chosen variables. Monthly data for the following variables are collected:

- WTI [2] crude oil spot prices (dollars per barrel \$/bd): WTI_t;
- the 5-year US interest rate: r_t;
- the US\$/euro exchange rate: FX_t;
- the level of US oil imports (thousand barrels): Im_t;
- the total open interest in crude oil Futures contracts (number of contracts): OI_t;

[2] WTI is the benchmark for crude oil spot prices and the underlying commodity of the NYMEX's oil future contracts (Geman (2005)).

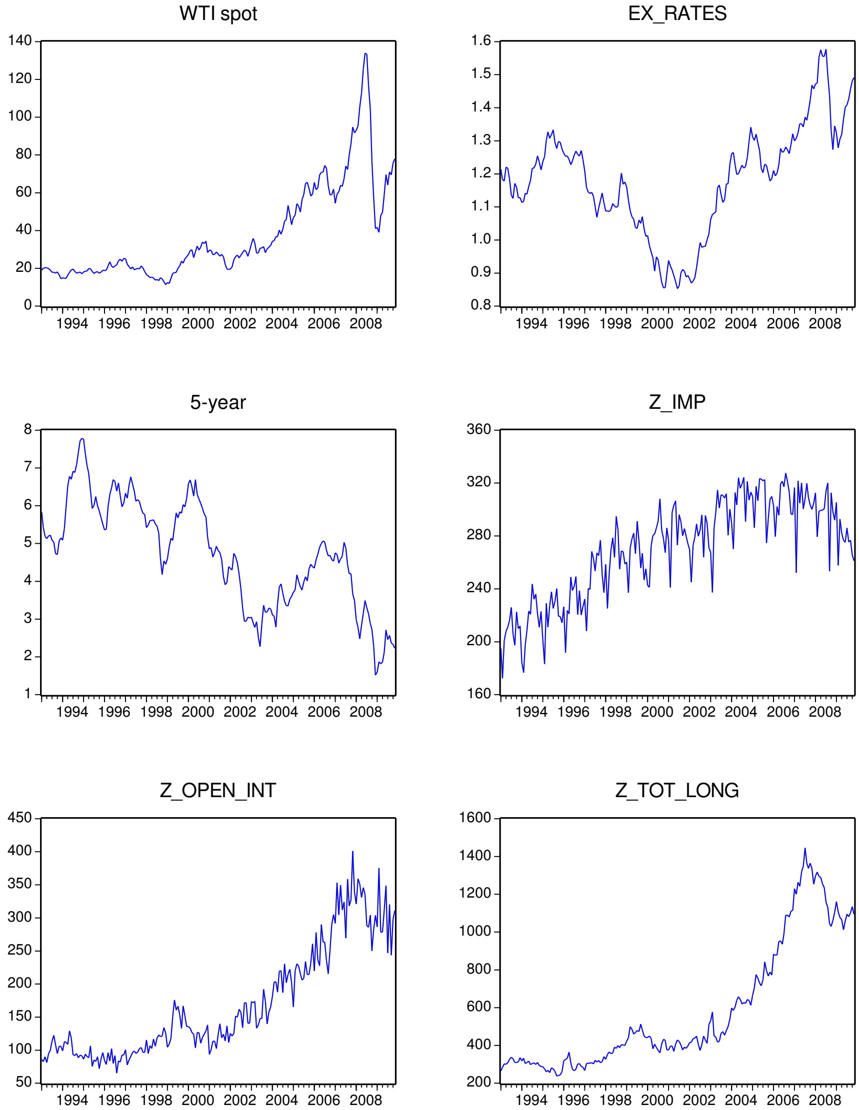

Figura 1. Data (1993-2009).

- the gold spot price: G_t.

In Figure 1 the graphs of the dynamics for the six variables are represented. The similar behavior of gold and oil prices during the entire interval can be easily detected, in line with recent findings in the literature (Malliaris and Malliaris (2009)). Some attention must be paid to the relationship between oil prices and exchange rates which show a very similar pattern after the introduction of the Euro (1999) while a perfect inverse relationship may be detected during the period 1993-1999. Before the introduction of the Euro, oil prices were mainly driven by demand factors, US economy was growing fast and in a stable environment, the US$ was appreciating and so exchange rate was not directly affecting oil price changes. The futures trading, measured in terms of open interests, shows also a arge increase after the 2000, but a direct correlation with oil price changes has to be verified. In table 1 the main statistical features for the mentioned variables are reported.

3.2 Stationarity of the data

When dealing with financial prices it is standard procedure to transform the data in log, so we use the $ln(WTI)$, $ln(G_t)$ and the $ln(FX_t)$. Before we investigate the stationarity of each time series, we first implement tests of structural breaks. We do so because oil prices and exchange rates may have been affected by major events in the observed period. Failing to account for structural changes may bias the tests for stationarity. We apply the tests proposed by Bai and Perron (1998, 2003), which allow for multiple structural changes[3]. As suggested by Bai and Perron (2003), a useful strategy is to first examine the double maximum UDmax or WDmax tests to see if at least one break is present given some upper bound, M. The null hypothesis is that there is no structural break, and the alternative is that there are an unknown number of breaks. The maximum number of structural changes allowed was chosen to be three (M=3). According to the results from the UDmax or WDmax tests, the null hypothesis of no structural break is not rejected at the 5% significant level for all the series. Given no evidence of the presence of structural breaks, we test for unit roots using the Augmented DickeyFuller (ADF) test as well as the test (M-tests) proposed by Ng and Perron (2001) based on modified information criteria (MIC): the modified Phillips-Perron test (PP). According to the unit root tests, all variables are integrated of order one ($I(1)$). This result is consistent with well-documented evidence of the nonstationary behavior of exchange rates, oil prices, gold prices, interest rates, US oil imports and open interests. The results of the unit root tests for the time series in levels, Y_t, and first difference, ΔY_t are reported in Table 2.

3.3 The VECM framework

The relationship between the examined variables is analyzed using a cointegration approach given that the standard procedures of inference -the standard regression results and the correlation measure- can be significantly biased when we deal with integrated variables. So we use a Vector Error Correction Model (VECM)[4] framework to capture stochastically a long run equilibrium between a set of non-stationary variables.

A set of n economic variables are cointegrated if one or more linear combinations of them is stationary, even though individually the variables are not stationary. Using Johansen approach (see i.e., Johansen (1988), Johansen (1994) and Stock and Watson (1988)), based on Vector AutoRegressive (VAR) model, we search for all possible cointegrating relationships.

Assume that the n-vector of non-stationary $I(1)$ variables Y_t follows a vector autoregressive (VAR) process of order p,

[3] The GAUSS code is available at: http://qed.econ.queensu.ca/jae/2003-v18.1/bai-perron/.

[4] The VEC specification only applies to cointegrated time series and is based on the so-called reduced rank regression method (i.e., see Johansen (1995)).

Tabella 2
Unit root test results.

	WTI_t	r_t	FX_t	Im_t	OI_t	G_t
Series in level						
ADF	−0.80	−0.96	0.15	0.85	0.84	2.10
	(0.85)	(0.76)	(0.66)	(0.55)	(0.56)	(0.99)
PP	−0.75	−1.09	−0.17	0.93	0.85	2.32
	(0.87)	(0.24)	(0.62)	(0.71)	(0.89)	(0.99)
Series in first differences						
ADF	−6.52	−10.17	−10.41	−2.65	−16.09	−15.14
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
PP	−8.71	−10.16	−10.35	−3.86	−12.26	−15.14
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Note: p-values are provided in parenthesis. The lag length was selected by using the Schwarz Information Criterion (SIC).

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \ldots + A_p Y_{t-p} + \epsilon_t \tag{1}$$

with ϵ_t as the corresponding n-dimensional white noise, and $n \times n$ A_i, $i = 1, \ldots, p$ matrices of coefficients [5] . Eq. (1) is equivalently written in a VECM framework,

$$\Delta Y_t = D_1 \Delta Y_{t-1} + D_2 \Delta Y_{t-2} + \ldots + D_p \Delta Y_{t-p+1} + D Y_{t-1} + \epsilon_t \tag{2}$$

where $D_i = -(A_{i+1} + .. + A_p)$, $i = 1, 2, \ldots, p-1$ and $D = (A_1 + .. + A_p - I_n)$. The Granger's representation theorem asserts that if D has reduced rank $r \in (0, n)$, then $n \times r$ matrices Γ and B exist, each with rank r, such that $D = -\Gamma B'$ and $B' Y_t$ is $I(0)$ [6] . r is the number of cointegrating relations and the coefficients of the cointegrating vectors are reported in the columns of B. If $r < n$, there are $n - r$ common trends among the variables and r linear combinations (stationary cointegrating relations).

The existence of cointegrating relationship may capture the regularities of some financial and economic variables that deviate around some average (equilibrium) value. In other words the series are drifting together at roughly the same rate, i.e., they have the same long wave or common (stochastic) trend.

[5] In the following, for the VAR(p) model we exclude the presence of exogenous variables.
[6] $-\Gamma$ is the matrix of adjustment coefficients which has dimension $n \times r$ and the coefficients, γ_i, describe the speed of adjustment of the particular series Y_t to deviation from the cointegration relationship, i.e., the equilibrium errors.

4 The long run equilibrium

Using a vector of 6 variables, $Y_t = [WTI_t, r_t, OI_t, Im_t, FX_t, G_t]$, represented by monthly data collected over the period January 1993-December 2009, we run the Johansen test to investigate the presence of cointegrating relationships.

The results of the test are reported in Table 3. A rejection of the null 'no cointegrated' relationship in favor of 'r at most 1' at the 1% significance level is provided, so one cointegrating relationship ($r = 1$) among the variables is found. In this case the cointegrating vector, v_t is unique and $I(0)$ and can be expressed as $v_t = B'Y_t$,

$$v_t = B_0 + B_1 WTI_t + B_2 r_t + B_3 OI_t + B_4 Im_t + B_5 FX_t + B_6 G_t \quad (3)$$

A long run equilibrium among oil, exchange rate, interest rate, gold, US oil imports and futures trading exists and is defined by the following coefficients:

$$v_t = -9.29 - 0.013WTI_t + 0.016r_t - 10.57OI_t + 10.73Im_t + 0.001FX_t + 0.011G_t \quad (4)$$

Given that we have one cointegrating vector we wish to identify it uniquely in order to provide an economic/financial interpretation. We normalize on a variable which is "representative" for the relation we want to study: the oil price, and try to identify possible restrictions required for other variables. Examining the single variables dynamics we want to carefully understand the role played by the exchange rate during the chosen interval. In particular, given the non stationarity of the variables the simple correlation measure between oil prices and exchange rates provides biased results - linear correlation coefficient, $\rho_{(WTI),(FX)}$, over the entire period results equal to 0.722, while over the first sub-interval it is -0.4. In order to have a valid measure of the relationship existing between the two variables, following Amnno and Norden (1998), we test for cointegration between the two variables. Using an Engle Granger[7] framework in the case of two variables we find that the two series are cointegrated and the normalized cointegration coefficient is $\beta = 2.8$. So we set the just-identifying restrictions to normalize respect to oil price: $B_1 = 1$ and $B_5 = -2.8$ to obtain:

$$WTI_t = \theta_1 + \theta_2 r_t + \theta_3 OI_t + \theta_4 Im_t + \theta_5 FX_t + \theta_6 G_t + \eta i \quad (5)$$

where $\theta i = -\frac{B_i}{B_1}$ for $i = 2, .., 6$ and $\eta_i = -\frac{v_t}{B_1}$.

The estimated coefficients for equation 5, given the chosen restrictions, are reported in table 4. So we can specify:

[7] In an Engle-Granger framework given two price series $Y_{1,t}$ and $Y_{2,t}$, both $I(1)$, the "cointegration regression", $Y_{1,t} = \alpha + \beta Y_{2,t} + z_t$, is estimated to fit equilibrium relationship. The Ordinary Least Squares (OLS) residuals z_t from the cointegrating regression are estimates of the equilibrium errors.

Tabella 3
Cointegration rank test (1993-2009).

Nr. of coint. vec.	Eigenvalue	λ_{trace}	$\lambda^{0.05}_{\text{trace}}$	λ_{max}	$\lambda^{0.05}_{\text{max}}$
$r = 0$	0.206	98.05	95.75	45.76	40.08
$r \leq 1$	0.095	52.28	69.82	19.92	33.87
$r \leq 2$	0.062	32.37	47.86	12.75	27.58
$r \leq 3$	0.051	19.62	29.79	10.26	21.13
$r \leq 4$	0.043	9.36	15.49	8.79	14.26
$r \leq 5$	0.0028	0.57	3.84	0.56	3.84

$$WTI_t = -43.95 + 0.44 r_t - 0.04 OI_t + 0.06 Im + 2.80 FX_t + 5.37 G_t + \eta_i \tag{6}$$

A likelihood ratio test of the set of overidentifying restrictions produces the statistic $\chi^2 = 10.41$ with a p-value of 0.0012 so that the set of restrictions are accepted.

All the coefficients result statistically significant at a 5% level. The equilibrium relationship shows that oil prices are positively affected by the macroeconomic variables we considered: FX_t, Im_t, r_t. An increase in exchange rate, FX_t or in the level of oil imports causes an increase in the oil price. Also gold influences positively the oil price, in line with previous findings, showing a direct relationship between these two variables, $\theta_6 = 5.37$. The only variable which results to have negative impact on oil prices is the futures trading, with $\theta_3 = -0.04$. Open interest provides information on the use of Futures contracts in the oil market, futures trading increase is due mainly to hedging and risk managing purposes. Over the last decade Futures trading experienced a huge increase showing how this commodity has become a crucial asset for investment and hedging purposes. Banks, Fund Managers and investors started to trade in oil futures in addition to the traditional oil retailers and manufacturers. However, the increase of the Futures trading seems to have more an informative role in the long run providing an efficient tool to control oil price fluctuations.

Overall, given the cointegrating equation all the variables play a statistically significant role and in the long run all these variables contribute to bring the oil price back toward equilibrium. Looking at the size of the single cointegrating coefficients it is interesting to notice that the coefficient for gold has the largest value, θ_6, followed by the imposed coefficient for exchange rate θ_5. It can be said that these two variables are the key drivers towards the equilibrium and we may also test for weak exogeneity of the two. If we look at the "loading factors" or adjustment vector, Γ, we see that the coefficients in the fifth and sixth raw, γ_5 and γ_6, are not significant while the other are all statistically significant. We may partition the adjustment vector as

Tabella 4
VEC results, 1993-2009.

Series	Estimated coefficients θ_i	Unrestricted adjustment parameters γ_i
WTI_t	1.00	$1.63E-05$
		[0.003]
r_t	-0.44	0.013
	[-2.004]	[0.89]
OI_t	0.04	-3.95
	[4.19]	[-3.21]
Im_t	-0.06	3.66
	[-5.98]	[3.78]
FX_t	-2.80	0.001
		[0.90]
G_t	-5.37	0.004
	[-3.59]	[1.79]
C	43.95	

Note: t-statistics are provided in parenthesis []. An intercept C is included in the test equation.

$$\Gamma = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \\ 0 \\ 0 \end{bmatrix}$$

and test for the null $H_0 : \gamma_5 = \gamma_6 = 0$. As shown by the t-statistics reported in table 4 the null hypothesis cannot be rejected so gold and the exchange rate appear to be weakly exogenous with respect to the cointegration coefficients, β_i and the other adjustment coefficients, γ_i, $i = 1, 2, 3, 4$. This implies that gold and the foreign exchange rate influence the oil prices. The null H_0 that the cointegration relation is not present in the equation determining gold and foreign exchange cannot be rejected.

5 Conclusion

The relationship between WTI crude oil spot prices and a set of macroeconomic and financial variables are investigated using a VECM framework. A long run equilibrium among the chosen variables is found: the US dollar/euro exchange rate, the medium term interest rate, the oil imports together with the gold price and the futures trading all contribute to build a long run equilibrium respect to the oil price fluctuations which may only be temporarily perturbed. The main role seems to be played by the exchange rate and the gold price. The two variables , gold and the foreign exchange rates, are found to be weakly exogenous respect to the long run equilibrium relationship. This means that gold and foreign exchanges fluctuations may be independent by the cointegrating relationship and we may state that they represent the main drivers of oil volatility.

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