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Oil price dynamics, macro-finance interactions and the role of financial speculation

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Abstract

What is the role of financial speculation in determining the real oil price? We find that while macroeconomic shocks have been the major upward driver of the real oil price since the mid 1980s, also financial shocks have sizably contributed since early 2000s, and at a much larger extent since mid 2000s: over the period 2004:1 through 2010:3, the real oil price increased 65%; of the latter, 33% is related to fundamental financial shocks, 11% to non fundamental financial shocks, with macroeconomic and oil market supply side shocks contributing with a 5% and 3% increase, respectively. Yet, it would be inaccurate describing the *third oil price shock* as a purely *financial* episode: macroeconomic shocks largely accounted for the 65% real oil price run up over the 2007(2)-2008 (2) period, and similarly for the -67% and -31% contractions in 2008(4) and 2009(1); only over the 2009(2) through 2009(4) period macroeconomic and financial shocks

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equally contributed to the 54% real oil price increase. Hence, while we find support to the demand side view of real oil price determination, we also find a much larger role for financial shocks than previously noted in the literature.

Keywords: Oil price, financial speculation, macro-finance interface, international business cycle, factor vector autoregressive models.
JEL classification: C22; E32; G12

1 Introduction

After about two decades of stability, both nominal and real oil prices have been increasing since 2003 (US$ 30 per barrel), with unprecedented volatility in 2008, as nominal oil prices peaked up at US$ 140 in July, to bottom down at US$ 40 in December; oil prices have mostly been increasing thereafter, achieving a new peak in April 2011 (US$ 110), quoting about US$ 100 at the time of writing.

Recent oil price trends, hikes and volatility have indeed revived the debate on the factors contributing to oil price determination, and two main explanations for the *third oil price shock* have so far been proposed in the literature: firstly, increasing oil demand, due to rapid growth in emerging countries[1] and stable OECD oil consumption (Kilian, 2008, 2009a,b) or to expansionary monetary policies (Frankel, 2007; Barsky and Kilian, 2002, 2004), in the face of stagnant oil production[2]; secondly, increased speculation in the oil futures markets since mid 2000s (Davidson, 2008; Krugman, 2009, 2010; Singleton, 2011; Frankel and Rose, 2010; Juvenal and Petrella, 2011; Lombardi and Van Robays, 2011).

While the *economic growth* hypothesis posits recent oil price dynamics as being the consequence of *flow* oil demand and supply interactions, following ongoing upward shifts in demand, driven by strong macroeconomic fundamentals, the *excess liquidity* hypothesis refers to the effects exercised by monetary policy and real interest rates on the (fundamental) *financial* demand for oil, as well as on the oil supply, and then on the real oil price through inventories management;[3] differently, the *excess speculation* hypoth-

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[1] Brazil, China, Hong Kong, India, Singapore, South Korea, Taiwan and Thailand accounted for 135% of the oil consumption increase between 2005 and 2010. Yet, just 43% over the period 1998 through 2005.

[2] Since 2005 both OPEC and non-OPEC countries oil production has been stagnating: the oil supply average yearly rate of growth was 1.8% (3%, OPEC; 2%, NON OPEC) over the period 2000-2004; yet, just 0.5% (0.3%, OPEC; 0.6%, NON OPEC) over the period 2005-2010.

[3] A related argument is concerned with the evolution over time of energy intensity, i.e. the value share of energy consumption over GDP. The latter depends crucially on both the price and income elasticities of oil demand. While the short-run price elasticity is close to zero, income elasticity is tipically below one at a later stage of the industrialization process (currently about 0.5 for the US; Hamilton, 2009a) and close to unity at earlier stages of industrial development. The former feature implies that, for a given income level, the energy share moves in the same direction of the oil price; the latter feature implies that, for a given relative price of oil, as the level of real income increases, the energy share follows a downward trend for industrialized countries and an upward trend for emerging countries. The combined effect of the two latter features would therefore explain increasing energy share dynamics for emerging countries over the sample investigated, as well as the

esis points to *non fundamental-driven* (speculative) inventories management, and therefore to the contribution of the *non-fundamental* component of financial oil demand.

While strong empirical support for the economic growth hypothesis has been found in the literature (Kilian and Murphy, 2010; Kilian and Hicks, 2011; Hamilton 2009a,b, Baumeister and Perssman, 2008; Dvir and Rogoff, 2010)[4], yielding quite a distinctive feature to the recent oil price shock, the traditional view positing flow oil supply, rather than flow oil demand, as the main determinant of historical oil price shock episodes (Hamilton, 2009b, 2011), the empirical evidence on the effects of financial speculation is not clear-cut.

The narrative evidence on the contribution of financial speculation to recent oil price dynamics is based on the steady increase in the market share of non hedging open interest positions in the US commodity futures and option markets. Since 2002 the Working's T index for the oil futures market (1.04 in 2002:1) has been increasing at an average 1.6% annualized rate, reaching 1.17 in 2010:3 (the last observation in the sample). Moreover, while historically the oil futures market has been in general *backwardation* over the 1980s and 1990s, since 2005 a *contango* condition has prevailed: the increased presence of non-commercial investors, seeking portfolio diversification in the oil futures market, might have indeed lead to a reversal in the receipt of the premium, i.e. from arbitrageurs to oil producers, rather than the other way around, as it would be theoretically expected (Hamilton and Wu, 2011). This might also be indicative of a structural shift in inventories management, as contango (backwardation) is in general associated with a high (low) level of inventories, which may indeed be induced by speculative behavior (Gorton et al., 2008). Alquist and Kilian (2010), within the framework of a fully endogenous model for the oil spot and futures price and inventories, actually document that the twelve-month oil futures spread ($future_t^{12} - spot_t$) is strictly related to precautionary/speculative oil demand shocks; yet, the

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trend reversal for industrialized countries since 2003, yielding an additional explanation for the recent oil price episode (Kilian, 2009).

[4] The latter view has however been challenged by Barsky and Kilian (2002, 2004) and, more recently, by Kilian (2008, 2009a,b), Kilian and Murphy (2010a, 2010b) and Kilian and Hicks (2011), showing that demand shocks would have shaped low frequency trend real oil price dynamics since the 1970s, while *speculative* demand and supply shocks would have only contributed to high frequency cyclical deviations from trend. But indeed, *not all oil price shocks are alike*, and the taxonomy of oil price shocks proposed in Kilian (2009a) and Kilian and Murphy (2010a), has provided interesting insights also on the most recent episode. Yet, even for the 2008 episode, controlling for changing refinery utilization rates and non-linear effects of OPEC capacity utilization might be relevant (Dees et al., 2007, 2008).

latter linkage would have undergone structural change since 2004, feature which may be related to the increased financialization of the oil market.

There are few *fundamental* financial transmission mechanisms which can be posited to explain the transmission of liquidity shocks to the real oil price: firstly, excess liquidity may lead to an increase in the demand for oil as a financial asset through a portfolio rebalancing mechanism; secondly, a contraction in the real interest rate may lead to a portfolio shift from bonds to (perceived) more profitable assets, i.e. oil and other commodities, housing-related securities and stocks (Frankel, 2007; Calvo, 2008); thirdly, by lowering the cost of holding inventories for traders and slowing down the rate of extraction for producers (Hotelling, 1931); fourthly, as the real oil price may be measured as the net present value of the expected future stream of convenience yields (Pindyck, 1993), a contraction in the real interest rate would lead to lower discounting and therefore a higher real oil price; fifthly, according to a Dornbusch-type monetarist overshooting mechanism a monetary expansion would drive the real interest rate down and the real oil price up, over its equilibrium value, as much as it is largely considered overvalued and there are expectations of future depreciation offsetting the lower real interest rate (Frankel, 2007); finally, as oil is valuated in US$, a generalized depreciation of the US$ might lead to a proportional increase in the real oil price, as OPEC might manage the oil supply in order to maintain unchanged the purchasing power of oil.

The empirical evidence in favor of the excess liquidity channel is weak. For instance, Barsky and Killian (2002) point to a positive linkage between liquidity conditions and the real oil price over the 1970s. Similarly Thomas et al. (2010), also finding a negative linkage with the VIX index, used to proxy for risk aversion, consistent with the existence of a demand for oil as a financial asset; yet, the contribution of both variables to real oil price dynamics would be small, and more likely to operate indirectly through the impact on real economic activity, as in Kilian and Barsky (2002); similarly also Frankel and Rose (2010), finding little evidence of a direct role for real interest rates in explaining oil price dynamics, beyond any effect exercised through real activity and inflation. Moreover, as the impact of liquidity on the real oil price would only be transitory, it is unlikely to account for the 2008 episode (Erceg et al., 2011; see also Kilian, 2010). Finally, Gillman and Nakov (2009) find that US inflation would Granger-cause nominal oil prices since 1973, and similarly Alquist et al. (2011), also concerning US monetary aggregates. Yet, differently from other financial assets, i.e. stocks, bonds and exchange rates, daily WTI oil prices and US gasoline retail prices would not react to US macroeconomic news (Kilian and Vega, 2009).

The presence of heterogeneous agents in the oil futures market is a crucial condition for financial speculation to be destabilizing. In fact, while arbitrageurs trade on the basis of information about fundamentals, therefore contributing to price discovery, noise traders trade on the basis of irrelevant information, creating drifts in the price process. Albeit heterogeneous behavior in the oil futures market has actually been documented in various papers (Vansteenkiste, 2011; Reitz and Slopek, 2008; ter-Ellen and Zwinkles, 2010; Ciffarelli and Paladino, 2010), the empirical evidence on the effects of financial speculation in the oil futures market is controversial.

Few studies, based on U.S. Commodity Futures Trading Commission (CFTC) daily data, would suggest that speculation in the oil futures market, since mid 2000s, would have not been destabilizing. For instance, there would not be any evidence of Granger causality from trading positions to futures oil prices, but actually some support to the view that oil prices lead trading positions; also, both hedging and non-hedging traders in the oil futures market would feature herding behavior (Buyuksahin and Harris, 2009); moreover, herding behavior by hedge funds, by being countercyclical, would have not been destabilizing (Boyd et al., 2009). Also, financial speculation would have contributed to stabilizing oil futures price volatility (Brunetti et al., 2010) and increased oil futures market liquidity (Buyuksahin et al., 2008). Kilian and Murphy (2010), using monthly data, within the framework of a structural vector autoregressive model, also find evidence against any role of financial speculation in the recent oil price episode.

Differently, using weekly CFTC data, Singleton (2011) finds that the thirteen-week change in the imputed positions of index investors and in the managed-money spread positions would predict weekly oil futures price returns since 2006. Frankel and Rose (2010), using annual data, also find some supporting evidence that herding behavior by financial speculators may have contributed to the 2008 price hike. Additional evidence in favor of a sizable contribution of financial speculation to oil price determination is also provided by Lombardi and Van Robays (2011) and Juvenal and Petrella (2011) using quarterly data. For instance, Lombardi and Van Robays (2011) find that speculative (non fundamental) financial shocks might have determined a 10% overshooting in the real oil price between 2007:8 and 2008:6, and then a 20% undershooting between 2008:7 and 2008:12. Also, Juvenal and Petrella (2011) find that speculative financial shocks might account for about 15% of the oil price increase between 2004 and 2008, particularly between 2006-2007, yet not contributing to the oil price decline in 2008.

In the light of the contrasting empirical evidence, the current paper then aims at assessing the contribution of financial speculation to recent oil price dynamics, providing original contributions under different perspectives.

Firstly, rather than using a small scale vector autoregressive (VAR) model, we investigate real oil price determinants by means of a very large scale macroeconometric model, set in the factor vector autoregressive (FVAR) framework, counting over 800 equations. The model consists of a two-block specification, and a novel inferential procedure is employed for estimation.

Secondly, our sample includes macro-financial data for fifty countries, including OECD and emerging economies, and a detailed description of the oil market (total consumption and production, reserves, inventories, refinery margins, the *real* oil price, *nominal* oil price volatility) and oil futures market conditions (Working's T index, the 12-month futures market basis). Single country macro-financial data are actually employed to estimate 12 *unobserved* factors (employment and the unemployment rate, real activity, the fiscal stance, core inflation, real wages, excess liquidity, the real short term rate and the term spread, real housing and stock prices, an US$ exchange rate index), describing global macroeconomic and financial conditions; 11 additional *observed* US financial factors, proxying for expectations about future fundamentals and economic/financial fragility conditions are also considered: in particular, the US fiscal and trade deficit to GDP ratios, stock market S&P500 volatility, the size and value Fama-French factors, the Carhart momentum factor, the Pastor-Stambaugh liquidity factor, the Adrian-Etula-Muir leverage factor, the real IMF non-energy commodities price index, real gold prices and the Bagliano-Morana economic/financial fragility index, are considered.

The careful modelling of the oil market macro-finance interface surely is an important novelty of our study, as we are unaware of previous contributions seeking such an in depth understanding of macro-financial interactions within the oil market. While Kilian and Murphy (2010), by including inventories in their model, do allow for a financial oil demand component and, indirectly, for the effect of future fundamentals on oil demand, our contribution, by conditioning on risk factors, is the first attempt to *directly* measuring their effects. By including measures of excess speculation, our study also aims at disentangling the fundamental and non fundamental components of financial oil demand, which are left indistinct in Kilian and Murphy (2010). We do find that without a careful description of the *financial side*, *shocks* and *transmission mechanisms* which are important to the understanding of the working of the oil market would go neglected.

Thirdly, the proposed modelling approach leads not only to confirm previous evidence, but also to important new insights on the determination of the real oil price.

To briefly overview the main results of the paper, we find that, at least since the mid-1980s, the real oil price has been strongly endogenous and mainly demand driven, with both macroeconomic and financial shocks sizably contributing to oil price dynamics, consistent with the relevance of both flow and financial oil demand components. While, macroeconomic shocks were the major upward driver of the real oil price over the whole period investigated, financial shocks sizably contributed to increasing the real oil price since early 2000s as well, and even more since mid 2000s; similarly oil market supply side shocks since early 2000s, albeit at a much smaller extent than macroeconomic shocks. Macroeconomic and fundamental financial shocks also contributed to stabilizing nominal oil price volatility over the whole period investigated, and non fundamental financial shocks as well since mid 2000s; differently, oil market supply side shocks have been the major upward driver of nominal oil price volatility.

Moreover, of the 65% real oil price increase over the period 2004:1 through 2010:3, 33% is related to fundamental financial shocks and 11% to non fundamental financial shocks; macroeconomic and oil market supply side shocks contributed with a 5% and 3% increase, respectively. Yet, despite the large contribution of financial shocks, it would be inaccurate describing the third oil price shock as a purely *financial* episode. The 2007-2009 episode is a *macro-finance* episode: macroeconomic shocks accounted for 58% of the 68% real oil price run up over the 2007(2)-2008 (2) period, while the contribution of financial shocks was sizable (6%) only in 2007(4); moreover, the -67% contraction in 2008(4) and the -31% contraction in 2009(1) are largely accounted for by macroeconomic shocks (-40% and -26%), with financial shocks (-14% and -7%) also sizably contributing; only over the 2009(2) through 2009(4) period macroeconomic (21%) and financial (20%) shocks equally accounted for the 54% real oil price increase.

Overall, while we provide support to the demand view of the real oil price determination, we do also find a larger role for financial shocks than previously noted in the literature.

After this introduction, the paper is organized as follows. In Section 2 the econometric methodology is introduced, while in Section 3 the data are presented. Then, in Section 4 specification and estimation issues are discussed, while in Section 5, 6 and 7 the empirical results are presented. Finally, conclusions are drawn in Section 8.

2 Econometric methodology

The econometric model is described by two blocks of equations. The former refers to the *observed* ($\mathbf{F}_{2,t}$) and *unobserved* ($\mathbf{F}_{1,t}$) global macro-financial factors and oil market demand and supply side variables ($\mathbf{O}_t$), collected in the $r \times 1$ vector $\mathbf{F}_t = \left[\mathbf{F}'_{1,t}\ \mathbf{F}'_{2,t}\ \mathbf{O}'_t\right]'$, while the latter to q macro-financial variables for m countries ($n = m \times q$ equations in total). The joint dynamics of the "global" macro-finance-oil market interface (the global economy thereafter) and the "local" macro-finance interface are then modelled by means of the following reduced form dynamic factor model

$$\begin{aligned} (\mathbf{I} - \mathbf{P}(L))(\mathbf{F}_t - \boldsymbol{\kappa}_t) &= \boldsymbol{\eta}_t & (1) \\ \boldsymbol{\eta}_t &\sim i.i.d.(\mathbf{0}, \boldsymbol{\Sigma}_\eta) & (2) \\ (\mathbf{I} - \mathbf{C}(L))\left((\mathbf{Z}_t - \boldsymbol{\mu}_t) - \boldsymbol{\Lambda}\ (\mathbf{F}_t - \boldsymbol{\kappa}_t)\right) &= \mathbf{v}_t & (3) \\ \mathbf{v}_t &\sim i.i.d.(\mathbf{0}, \boldsymbol{\Sigma}_v). & (4) \end{aligned}$$

The model is cast in a weakly stationary representation, as $(\mathbf{F}_t - \boldsymbol{\kappa}_t)$, $(\mathbf{Z}_t - \boldsymbol{\mu}_t) \sim I(0)$, where $\boldsymbol{\mu}_t$ and $\boldsymbol{\kappa}_t$ are $n \times 1$ and $r \times 1$ vectors of deterministic components, respectively, with $r \leq n$, including an intercept term, and, possibly, linear or non linear trends components.

Global dynamics are described by the stationary finite order polynomial matrix in the lag operator $\mathbf{P}(L)$, $\mathbf{P}(L) \equiv \mathbf{P}_1 L + \mathbf{P}_2 L^2 + ... + \mathbf{P}_p L^p$, where $\mathbf{P}_j$, $j = 1, .., p$, is a square matrix of coefficients of order r, and $\boldsymbol{\eta}_t$ is a $r \times 1$ vector of i.i.d. reduced form shocks driving the $\mathbf{F}_t$ factors. The contemporaneous effects of the global factors on each country variables in $\mathbf{Z}_t$ are measured by the loading coefficients collected in the $n \times r$ matrix $\boldsymbol{\Lambda} = \left[\boldsymbol{\Lambda}'_{F_1}\ \boldsymbol{\Lambda}'_{F_2}\ \boldsymbol{\Lambda}'_{O}\right]'$. Finally, $\mathbf{C}(L)$ is a finite order stationary block (own country) diagonal polynomial matrix in the lag operator, $\mathbf{C}(L) \equiv \mathbf{C}_1 L + \mathbf{C}_2 L^2 + ... + \mathbf{C}_c L^c$, where $\mathbf{C}_j$, $j = 0, .., c$, is a square matrix of coefficients of order n, and $\mathbf{v}_t$ is the $n \times 1$ vector of i.i.d. reduced-form idiosyncratic (i.e. country-specific) disturbances. It is assumed that $E\left[\eta_{jt} v_{is}\right] = 0$ for all i, j, t, s.

The specification of the model in (1)-(3) embeds a set of important assumptions on the structure of global and local linkages: (i) global shocks ($\boldsymbol{\eta}_t$) affect both the global and local economy through the polynomial matrix $\mathbf{P}(L)$ and the factor loading matrix $\boldsymbol{\Lambda}$; (ii) idiosyncratic disturbances ($\mathbf{v}_t$) do not affect the global economy, while impact on the local economy only through own-country linkages.

2.1 Estimation

The two-block specification is estimated by means of a two-stage approach.

Firstly, consistent and asymptotically Normal estimation the set of equations in (3) is obtained following the iterative procedure proposed in Morana (2011a); the latter bears the interpretation of QML estimation performed by means of the EM algorithm:

• An initial estimate of the r_1 unobserved common factors in $\mathbf{F}_{1,t}$ is obtained through the application of Principal Components Analysis (PCA) to subsets of homogeneous cross-country data $\mathbf{Z}_i = \{\mathbf{Z}_{i,1}, ..., \mathbf{Z}_{i,T}\}$, $i = 1, ..., r_1$, $r_1 \leq q$;[5] then, an initial estimate of the polynomial matrix $\mathbf{C}(L)$ and the factor loading matrix $\mathbf{\Lambda}$ is obtained by means of OLS estimation of the equation system in (3). This is performed by first regressing $\hat{\mathbf{F}}_t$ on $\boldsymbol{\kappa}_t$ to obtain $\hat{\boldsymbol{\kappa}}_t$; then the actual series $\mathbf{Z}_t$ are regressed on $\boldsymbol{\mu}_t$ and $\hat{\mathbf{F}}_t - \hat{\boldsymbol{\kappa}}_t$ to obtain $\hat{\mathbf{\Lambda}}$ and $\hat{\boldsymbol{\mu}}_t$; $\hat{\mathbf{C}}(L)$ is then obtained by means of OLS estimation of the VAR model for the gap variables $\mathbf{Z}_t - \hat{\boldsymbol{\mu}}_t - \hat{\mathbf{\Lambda}}\left(\hat{\mathbf{F}}_t - \hat{\boldsymbol{\kappa}}_t\right)$ in (3).

• In the E-step the unobserved factors $(\mathbf{F}_{1,t})$ are estimated, given the observed data and the current estimate of model parameters, by means of principal components analysis (PCA), i.e. a new estimate of the unobserved common factors in $\mathbf{F}_{1,t}$ is obtained by means of PCA applied to the filtered variables $\mathbf{Z}_t^* = \mathbf{Z}_t - \left[\mathbf{I} - \hat{\mathbf{C}}(L)\right]\hat{\mathbf{\Lambda}}_*\left(\hat{\mathbf{F}}_{*,t} - \hat{\boldsymbol{\kappa}}_{*,t}\right)$, with $\hat{\mathbf{F}}_{*,t} = \left[\mathbf{F}'_{2,t}\ \mathbf{O}'_t\right]'$, $\hat{\mathbf{\Lambda}}_* = \left[\hat{\mathbf{\Lambda}}'_{F_2}\ \hat{\mathbf{\Lambda}}'_O\right]'$ and $\hat{\boldsymbol{\kappa}}_{*,t} = \left[\hat{\boldsymbol{\kappa}}'_{F_2,t}\ \hat{\boldsymbol{\kappa}}'_{O,t}\right]'$.

• In the M-step the likelihood function is maximized (OLS estimation of the $C(L)$ matrix is performed) under the assumption that the unobserved factors are known, conditioning on their E-step estimate, i.e. conditional on the new unobserved common factors, a new estimate of the polynomial matrix $\mathbf{C}(L)$ and the factor loading matrix $\mathbf{\Lambda}$ is attained as described in the initialization step. Convergence to the one-step QML estimate is ensured, as the value of the likelihood function is increased at each step.

Secondly, consistent and asymptotically Normal estimation of the set of equations in (1) is performed by means of PC-VAR estimation (Morana, 2011b), treating the consistently estimated factors as they were actually observed. The latter is achieved in the following steps:

• PCA is applied to $\mathbf{x}_t \equiv \hat{\mathbf{F}}_t - \hat{\boldsymbol{\kappa}}_t$ and the first s PCs, $\hat{\mathbf{f}}_t$, are computed;

• the dynamic vector regression

$$\begin{aligned} \mathbf{x}_t &= \mathbf{D}(L)\hat{\mathbf{f}}_t + \boldsymbol{\varsigma}_t \\ \boldsymbol{\varsigma}_t &\sim I.I.D.\left(\mathbf{0}, \mathbf{\Sigma}_\varsigma\right), \end{aligned} \tag{5}$$

where $\mathbf{D}(L) \equiv \mathbf{D}_1 L + \mathbf{D}_2 L^2 + ... + \mathbf{D}_p L^p$ features all the roots outside the unit circle, is estimated by OLS to obtain $\hat{\mathbf{D}}(L)$;

• the (implied OLS) estimate of the VAR parameters in (1) is then obtained by solving

$$\hat{\mathbf{P}}(L)_{PCVAR} = \hat{\mathbf{D}}(L)\hat{\mathbf{\Xi}}'_s,$$

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[5] For instance, a stock return global factor can be estimated by means of the application of PCA to the vector of cross-country stock return data, and so on.

where $\hat{\boldsymbol{\Xi}}_s$ is the matrix of the eigenvectors associated with the first s ordered eigenvalues of $\hat{\boldsymbol{\Sigma}}$ ($\boldsymbol{\Sigma} = E\left[\mathbf{x}_t\mathbf{x}_t'\right]$).

2.2 Policy analysis

The structural vector moving average representation for the global model in (1) can be written as

$$(\mathbf{F}_t - \boldsymbol{\kappa}_t) = \mathbf{H}_F(L)\mathbf{K}^{-1}\boldsymbol{\xi}_t, \tag{6}$$

where $\boldsymbol{\xi}_t$ is the vector of the r structural shocks driving the common factors in $\mathbf{F}_t$, i.e. $\boldsymbol{\xi}_t = \mathbf{K}\,\boldsymbol{\eta}_t$, $\mathbf{K}$ is a $r \times r$ invertible matrix, and

$$\mathbf{H}(L) \equiv \begin{pmatrix} \mathbf{H}_F(L) & \mathbf{0} \\ \mathbf{H}_{FZ}(L) & \mathbf{H}_Z(L) \end{pmatrix} \equiv \left(\mathbf{I} - \mathbf{A}(L)\right)^{-1},$$

where $\mathbf{A}(L) = \begin{pmatrix} \mathbf{P}(L) & \mathbf{0} \\ [\boldsymbol{\Lambda}\mathbf{P}(L) - \mathbf{C}(L)\boldsymbol{\Lambda}] & \mathbf{C}(L) \end{pmatrix}$.

By assumption the structural factor shocks are orthogonal and have unit variance, so that $E\left[\boldsymbol{\xi}_t\boldsymbol{\xi}_t'\right] = \mathbf{K}\,\boldsymbol{\Sigma}_\eta\,\mathbf{K}' = \mathbf{I}_r$. To achieve exact identification of the structural disturbances, additional $r(r-1)/2$ restrictions need to be imposed. Since $\boldsymbol{\eta}_t = \mathbf{K}^{-1}\boldsymbol{\xi}_t$, imposing exclusion restrictions on the contemporaneous impact matrix amounts to imposing zero restrictions on the elements of $\mathbf{K}^{-1}$, for which a lower-triangular structure is assumed. This latter assumption implies a precise "ordering" of the common factors in $\mathbf{F}_t$. In particular, the first factor is allowed to have a contemporaneous impact on all other factors, but reacts only with a one-period lag to the other structural disturbances; instead, the last factor is contemporaneously affected by all structural shocks, having only lagged effects on all other factors. Operationally, $\mathbf{K}^{-1}$ (with the $r(r-1)/2$ zero restrictions necessary for exact identification imposed) is estimated by the Choleski decomposition of the factor innovation variance-covariance matrix $\boldsymbol{\Sigma}_\eta$, i.e. $\hat{\mathbf{K}}^{-1} = chol(\hat{\boldsymbol{\Sigma}}_\eta)$.

Forecast error variance and historical decompositions can then be obtained by means of standard formulas. Following the thick modelling strategy of Granger and Jeon (2004), median estimates of the parameters of interest, impulse responses, forecast error variance and historical decompositions, as well as their confidence intervals, robust to model misspecification, can be obtained by means of simulated implementation of the proposed estimation strategy. See the Appendix for a detailed account of the econometric methodology.

3 The data

We use seasonally adjusted quarterly macroeconomic time series data for 31 advanced economies (Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hong Kong, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, Taiwan, United Kingdom), 5 advanced emerging economies (Brazil, Hungary, Mexico, Poland, South Africa), and 14 secondary emerging economies (Argentina, Chile, China, Colombia, India, Indonesia, Malaysia, Morocco, Pakistan, Peru, Philippines, Russia, Thailand, Turkey), for a total of 50 countries. The (main) data source is IMF *International Financial Statistics*[6]

Concerning the block of equations in (3), for each of the 50 countries, apart from some exceptions, 17 macroeconomic variables are employed, namely *real GDP*, *private consumption* and *investment* growth, *public expenditure to GDP ratio* growth, *nominal bilateral US$ exchange rate* (value of 1 US$ in units of country currency) returns, *CPI inflation rate*, *M2 or M3 to GDP ratio* growth, *nominal M2/M3* growth, *civilian employment* growth, *unemployment rate* changes, *real wages* growth, *real stock prices* returns, *real housing prices* returns, *real short and long term interest rates*, *real effective exchange rate* returns, *bank loans to the private sector to GDP ratio* growth. For OECD countries the macro-financial sample extends from 1980:1 through 2010:3, while for non OECD countries only from 1995:1 through 2010:3. Different samples are therefore employed for the estimation of the block of equations in (3), i.e. 1980:1 through 2010:3 for the OECD countries block and 1995:1 through 2010:3 for the non OECD countries block.

Concerning the block of equations in (1), a total of 33 variables are considered in the vector $\mathbf{F}_t$.

Firstly, 12 variables are included in the vector of (global) observed factors $\mathbf{F}_{2,t}$, i.e. the Bagliano and Morana (2011) *US economic/financial fragility* index (FRA) in differences[7], the Fama and French (1993) *size* and *value*

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[6] Other data sources employed are FRED2 (Federal Reserve Bank of St. Louis); OECD and BIS (unofficial) house price data sets, and International Energy Agency (IEA-OECD) data sets.

[7] The economic and financial fragility index is computed as the common component in the TED, corporate and agency spreads. It is then directly related to credit and liquidity risk conditions. Hence, an increase in the index might signal a worsening in US economic and financial conditions.

factors (SMB, HML)[8], the Carhart (1997) *momentum* factor (MOM)[9], the Pastor and Stambaugh (1997) *stocks' liquidity* factor (PSL)[10], the S&P 500 stock return *volatility* in differences (FV)[11], the real *gold* price (GD) return, real IMF *non-energy commodities* price index returns (M), the *US fiscal* (Fd) and *trade deficit* (Td) *to GDP ratios* in differences, the Adrian, Etula and Muir (2011) *leverage* factor (LEV)[12]. The sample for the observed macro-financial factors extends from 1980:1 through 2010:3.

Secondly, 10 additional variables, concerning global oil demand and supply conditions have been included in the vector $\mathbf{O}_t$, namely *world oil re-*

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[8] The size factor is the difference between the returns on the small and big size portfolios; the value factor is the difference between the returns on the high and low book-to-market-ratio portfolios. Adverse economic conditions are reflected in negative size factor returns and positive value factor returns. In fact, as small firms are more risky, commanding a higher expected return, and are more strongly affected than large firms by adverse economic conditions, a negative return on the size factor might then be expected over economic downturns. Differently, as over economic downturns there is a *flight to quality*, i.e. investors shift from growth to value stocks, determining negative returns on the former and positive returns on the latter, a positive return on the value factor might then be expected.

[9] The momentum factor is the difference between the returns on the high and low prior perfomance (return) portfolios. The ranking is based on the cumulative return over the previous four quarters. As past performance is an indicator of future returns, the momentum factor can be expected to be larger over phases of economic expansion than downturn.

[10] The stocks' liquidity factor is the innovation in the average of the liquidity measure of individual stocks. The individual liquidity measure is the coefficient (beta) on the individual *order flow*, proxied by the signed volume, in a regression of the individual risk premium on the previous month individual return and previous month signed volume; volume is signed by the previous month individual risk premium. Then, the larger is the expected return reversal and the lower is stock's liquidity. Hence, the more negative is the individual order flow beta and the lower is stock's liquidity. The liquidity innovation is then computed by the scaled average of the individual stocks' liquidity innovation, computed as the first difference of the individual stocks' liquidity measure. The scaling factor is the ratio of previous month total value of the stocks considered in the average over the total value of the stocks as in August 1962. The quarterly series is then computed by averaging the monthly figures over each quarter.

[11] The volatility series is the square root of the S&P 500 conditional standard variance estimated by means of an asymmetric GARCH (1,1) model using monthly returns. The estimated monthly conditional variance has then been cumulated over each quarter in order to obtain a quarterly series. Stock market volatility is also employed as a measure of risk aversion, which is increasing with the level of price uncertainty.

[12] The leverage factor is computed by the ratio of total financial assets over the difference between total financial assets and total financial liabilities of security brokers-delears as reported in Table L.129 of the Federal Reserve Flow of Funds. It may be considered as a proxy for financial instability, i.e. the higher the leverage and the higher the fragility of the financial sector.

serves growth (R), net *world oil production changes* (increase: Pp, decrease: Pm)[13], *OECD oil refinery margins* growth (RM)[14], *world oil consumption* (C) growth, *OECD oil inventories* rate of growth (INV), *real WTI oil price* (OP) return, *nominal WTI oil price volatility* in differences (OV), the twelve-month *futures basis*, i.e. the ratio of the nominal twelve-month futures-spot spread over the nominal spot oil price (FB), and the growth rate of the oil futures market *Working* (1960)'s-T index (WT)[15]. The sample for the latter oil market variables extends from 1986:1 through 2010:3.

Thirdly, 11 variables have been collected in the vector of (global) unobserved factors $\mathbf{F}_{1,t}$; the latter are estimated using (3), as detailed in the methodological section. In particular, a first order own diagonal dynamic structure, as suggested by the BIC information criterion has been employed;[16] the global unobserved macro-financial factors are estimated as the first principal component extracted from subsets of homogeneous variable, i.e. a *real activity* factor (Y) from the real GDP, private consumption and investment growth series; a *fiscal stance* factor from the public expenditure to GDP ratio growth series (G); a global bilateral *US$ exchange rate* index from the various bilateral exchange rates against the US$ returns (X); a *nominal* (*core inflation*) factor (N) from the inflation rate and the nominal money growth, short and long term interest rate series; an *excess liquidity* index (L) from the M3(M2) to GDP ratio and the private loans to GDP ratio growth series; an *employment* factor (E) from the civilian employment growth series; an *unemployment rate* factor (U) from the unemployment rate in changes series; a *real wage* factor (W) from the real wage growth series; a *real stock market return* factor (F) from the real stock market price index return series; a *real housing return* factor (H) from the real housing price index return series; a *real short term rate* factor (SR) from the real short term interest rate series; a *term spread factor* (TS) from the term spread series.

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[13] A net positive change is measured by the maximum of (a) zero and (b) the difference between the log-level of the series for the current quarter and its maximum value in the previous four quarters. See Hamilton (1996), albeit for an application to the oil price.

[14] The refinery activity rate is computed as a consumption weighted average of OECD *refinery margins,* i.e. the *runs* over *capacity* ratios.

[15] The Working's T index is computed as $1+\frac{SS}{HS+HL}$ if $HS \geq HL$ and $1+\frac{SL}{HS+HL}$ if $HS < HL$, where SS and SL are the number of short and long speculative positions, respectively, and HS and HL are the number of short and long hedging positions, respectively. The index then yields a measure of *excess* speculation, relatively to hedging demand, in the futures market.

[16] $\hat{\mathbf{F}}_{1,t}$ has been obtained by conditioning with respect to $\mathbf{F}_{2,t}$ and only a subset of the variables considered in $\mathbf{O}_t$, i.e. the real oil price and the real non-energy commodities price index, which are avavilable since 1980:1. The other oil market variables are availble only since 1986:1.

Concerning the properties of the estimated factors, the stock return factor accounts for about 50% of total variance, and similarly the term spread factor; the nominal, exchange rate return and short term rate factors account for about 40% of total variance each; the real housing return factor accounts for about 30% of total variance, while the real activity, fiscal policy, employment, and unemployment rate factors for about 20% of total variance each; a lower proportion of total variance is finally accounted for by the excess liquidity (15%) and real wage (11%) factors, which should actually be interpreted in terms of OECD factors, mainly describing commonalities occurring more across OECD countries than across OECD and emerging countries. As macro-financial variables are available for emerging countries only since 1995, over the period 1980 through 1994 the factors reflect commonalities occurring across OECD countries only.[17]

4 The global oil market-macro-finance interface model: specification and estimation

The global model for the oil market macro-finance interface in (1) counts 33 endogenous variables, collected in the vector $\mathbf{F}_t = \left[\mathbf{F}'_{1,t}\ \mathbf{F}'_{2,t}\ \mathbf{O}'_t\right]'$. According to Monte Carlo results and specification tests, 12 principal components, jointly accounting for 80% of total variance, and three lags were selected for PC-VAR estimation. Hence, 36 parameters were estimated for each of the 33 equations in the model.[18]

The identification of the structural shocks has been performed by means of the Cholesky decomposition strategy described in the methodological section. The Choleski identification approach implies a recursive structural model, which ordering is assumed as follows: reserves, net oil production changes (negative and positive), refinery margins, employment and the unemployment rate, real activity, the fiscal stance, the US fiscal and trade deficit to GDP ratios, the nominal factor, real wages, oil consumption, excess liquidity, the real short term rate and term spread, real housing prices, the US$ exchange rate index, stock market volatility, the size and value Fama-French factors, the Carhart momentum factor, the Pastor-Stambaugh liquidity factor, the Adrian-Etula-Muir leverage factor, the Working-T speculative index, the futures market basis, oil inventories, the real oil price, nominal oil price volatility, the real non-energy commodities price index, real stock market

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[17] Detailed results on PCA and unit root testing are not included for reasons of space, but are available from the author upon request.

[18] Details are not reported for reasons of space; they are available upon request from the author.

prices, real gold prices and the Bagliano-Morana economic/financial fragility index.

As a caveat it should be recalled that the identified shocks may be sensitive to the ordering of the variables, requiring therefore economic motivations. The selected ordering is then based on the following rationale concerning the working of the oil market:

- the oil market supply side is constrained by geophysical conditions, reacting therefore with (at least one quarter) delay to macro-financial conditions;
- oil consumption is contemporaneously determined by the state of the world business cycle;
- inventories are contemporaneously affected by oil market demand and supply side conditions, as well as fundamental and non fundamental financial factors;
- the real oil price and nominal oil price volatility are contemporaneously determined by oil market supply side, flow and financial oil demand conditions, and inventories; they also react with delay to additional fundamental financial factors.

Moreover, concerning macro-financial interactions, it is assumed that:

- real activity, over the business cycle, is determined by labor market conditions, through a short-run production function;
- the fiscal/trade stance contemporaneously adjust to business cycle conditions;
- aggregate demand then feedbacks with delay to aggregate supply, and prices adjust according to their interaction;
- real wages contemporaneously react to aggregate demand and supply developments, and prices as well;
- the liquidity stance, set (by central banks) according to the state of the business cycle, contemporaneously determines the real short-term interest rate, also impacting on asset prices and financial risk;
- liquidity, consistent with a leaning-against-the-wind strategy followed by central banks, may then respond to asset prices and financial risk developments only with delay.

As the implied recursive structural model is exactly identified, the assumed restrictions cannot be tested. Yet, pairwise weak exogeneity testing can always be carried out to gauge further evidence on data properties. A joint test, based on the Bonferroni bounds principle, carried out using the 528 possible bivariate tests, implied by the recursive structure, which can be computed out of the 33 variables, would not reject, even at the 20% significance level, the weak exogeneity null hypothesis.[19]

Concerning physical oil market interactions, then eight structural shocks can be identified, i.e. an *oil reserves* shock, *net positive* and *negative production* shocks, a *refinery margins* shock, *oil consumption* and *inventories preferences* shocks, and *other real oil price* and *nominal oil price volatility* shocks.

The interpretation of the own shocks in terms of reserves, net production and refinery margins shocks is clear-cut, the latter accounting for about 100% of each variable fluctuations at the impact (see below for details). The interpretation of the oil consumption and inventories own shocks in terms of preferences shocks, depends on the former being net of the contemporaneous effect of the macroeconomic variables driving flow oil demand, and the latter also of the effect of the (financial) variables driving financial oil demand. Similarly for the real oil price and nominal oil price volatility own shocks, to which we do not attach an economic interpretation and simply refer as *other* real oil price and nominal oil price volatility shocks.

Moreover, concerning macroeconomic dynamics, eight structural shocks can be identified, i.e. an *aggregate demand* shock[20], a *labor supply* shock[21], a (*negative*) labor demand shock[22], a *productivity* shock[23], *US fiscal* and *trade*

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[19] The value of the test is 0.005 to be compared with a 20% critical value equal to 0.0004. Details are available upon request from the author.

[20] It accounts for 80% of real activity fluctuations in the very short-term, also exercising a positive impact on real activity (0.67% within two quarters and 0.29% in the long-term) and the nominal factor (0.02%, long-term). The above results, likewise for the interpretation of the other macroeconomic and financial structural shocks, are not reported for reasons of space. A full set of results is however available upon request from the author.

[21] It accounts for 90% of employment fluctuations in the very short-term, sizably contributing to real activity fluctuations in the short- to medium-term (up to 20%). The shock exercises a positive effect on employment (0.24% in the very short-term; 1.3% in the long-term) and real activity (0.64% in the short-term; 0.18% in the medium-term), as well as a negative effect on the unemployment rate (-0.92% in the short-term; -0.58% in the long term) and the real wage (–0.7% in the short-term; -1.3% in the long-term).

[22] It accounts for 90% of unemployment rate fluctuations in the very short-term. The shock exercises a positive effect on the unemployment rate (0.28% in the very short-term; 0.35% in the long-term) and a negative effect employment (-0.10% short-term), real activity (-0.07% in the very short-term; -0.17% in the long-term), and the real wage (-0.09% in the short-term; -0.33% in the long-term).

[23] It is the largest contributor to real activity long-term fluctuations (20%), exercising a positive stimulus on real activity at any horizon (0.3% at the 1-year horizon and 0.7% at the 10-year horizon) and a negative short-term impact on the nominal factor (-0.01%). It also positively impacts on the real short-term rate at any horizon (0.11% in the long-term).

deficit shocks[24], a (global) *fiscal stance* shock[25], and a *core inflation* shock[26].

Finally, concerning financial dynamics, seventeen structural shocks can be identified, i.e. an *excess liquidity* shock[27], a set of *speculative asset price (portfolio)* shocks, orthogonal to contemporaneous macroeconomic, liquidity and interest rates shocks, i.e. a *real stock market prices* shock, a *real housing prices* shock, a *real gold price* shock and a *real non energy commodity price index* shock[28]; an *US$ exchange rate index* shock[29], a *risk-free rate* shock[30], two oil futures market speculative shocks, i.e. *Working's-T* and *futures basis* shocks[31]; a set of *risk factors* shocks, orthogonal to contemporaneous macroeconomic, liquidity and interest rates shocks, measuring revisions in market expectations about future fundamentals, i.e. a *risk aversion* shock, *size*, *value*, *leverage*, *stocks' liquidity*, and *momentum* factor shocks[32], a *term*

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[24] The US fiscal deficit shock accounts for 85% of US fiscal deficit to GDP ratio fluctuations in the very short-term. It leads to a long-term contraction in employment (-0.37%), a short-term contraction in real activity (-0.23%) and to a temporary increase in the unemployment rate (0.25%). The US trade deficit shock accounts for 80% of US trade deficit to GDP ratio fluctuations in the very short-term. It leads to a long-term contraction in real activity (-0.4%) and a long-term increase in the unemployment rate (0.3%). The above dynamics are consistent with both shocks, by being net of the global aggregate demand, labor demand and supply, and fiscal stance shocks, signaling growing long-term global imbalances.

[25] It accounts for 58% of public expenditure to GDP ratio fluctuations in the very short-term. It leads to a permanent contraction in employment (-0.84%), real activity (-0.5%) and to a permanent increase in the unemployment rate (0.73%). By being net of the shocks accounting for the state of the global business cycle (aggregate demand, labor demand and supply shocks), it is related to *excess* public expenditure dynamics.

[26] It accounts for 60% of nominal factor fluctuations in the very short-term, exercising a negative impact on employment (-0.3%, long-term) and real activity (-0.24%, short-term), also increasing the unemployment rate (0.19%, short-term) and real wages (0.4%, long-term); it also triggers a permanent increase in the real interest rate (0.05%).

[27] It accounts for 35% of excess liquidity fluctuations in the very short-term and leads to a permanent contraction in the real short-term interest rate (-0.07%), as well as in the real long-term interest rate (-0.03%, implied by the 0.04% increase in the term spread following the shock.

[28] The shocks account for 21%, 68%, 24% and 38% of real stock market, housing, non energy commodities index and gold price fluctuations in the very short-term, respectively.

[29] It accounts for 50% of the US$ exchange rate index fluctuations in the very short-term.

[30] It accounts for 30% of short-term real interest rate fluctuations in the very short-term. Being net of the contemporaneous effect of macroeconomic and liquidity shocks, it may be interpreted in terms of a short-term bonds risk premium shock.

[31] They account for 55% (each) of Working's-T and futures basis fluctuations in the very short-term, respectively. Their interpretation in terms of oil futures market speculative shocks follows from their positive impact on both the oil futures and spot price, also affecting inventories at various horizons, in addition to being orthogonal to the set of macroeconomic and financial shocks driving flow and fundamental financial oil demand.

[32] They account for 60%, 54%, 56%, 35%, 51% and 54% of stock market volatility, size,

spread shock[33], and a *residual economic and financial fragility index* shock[34].

Supporting evidence for the proposed interpretation of the various structural shocks is also provided by the impulse response analysis.

5 Forecast error variance decomposition

Median forecast error variance decompositions have been computed up to a horizon of ten years (40 quarters). Results for the oil market variables are reported in Table 1, for selected horizons; for expository purposes, we denote as very short-term the horizon within 2 quarters, short-term the horizon between 1 and 2 years, medium-term the horizon between three and five years, and long-term the 10-year horizon. Rather than focusing on the contribution of each structural shock, results are discussed with reference to various categories of shocks, distinguishing among oil market supply side shocks (SUP: reserves, net negative and positive production, refinery margins), oil consumption preferences shocks (C), inventories preferences shocks (INV), macroeconomic shocks (MAC: labor supply and demand, aggregate demand, fiscal stance, US fiscal and trade deficit, core inflation and productivity), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, real housing prices, risk aversion, size, value, momentum, stocks' liquidity and leverage factors, real non-energy commodity price index, real stock prices, real gold prices, economic and financial fragility index, (other) nominal oil price volatility), US$ exchange rate index shocks (X), speculative/non fundamental financial shocks (SPC: Working's-T index, futures basis), (other) real oil price shocks (OP). In both cases the contribution of the own shock (OWN) is isolated from the overall contribution: for instance, with reference to oil reserves, the SUP category would not include the reserves variable, whose contribution is reported under the OWN category.[35]

5.1 Oil consumption and production

According to the results of the forecast error variance decomposition, oil consumption and production would be similarly *exogenous* in the very short-term, yet similarly *endogenous* already in the short-term. In fact, the own

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value, momentum, stocks' liquidity and leverage factors fluctuations, respectively, in the very short-term.

[33] It accounts for 64% of term spread fluctuations in the very short-term.

[34] It accounts for 15% of the economic and financial fragility index fluctuations in the very short-term. By being orthogonal to all the other shocks considered in the model, it then bears the interpretation of *residual* fragility shock.

[35] A full set of results is available upon request from the author.

shock would account for about 80% of oil consumption fluctuations in the very short-term and 60% at longer horizons; similarly for net oil production changes, i.e. 70% and 90% for negative and positive changes, respectively, in the very short-term, and about 50% in both cases since the two-year horizon. Macroeconomic shocks would sizably contribute to oil consumption fluctuations already in the very short-term (20% within 1-quarter), as well as in the medium- to long-term (16%); similarly for financial shocks (12%). Moreover, net oil supply contractions would be more affected by macroeconomic (20% since the 1-year horizon) than financial shocks (up to 18%), and the other way around for net oil supply increases (10% and up to 30%, respectively).

Overall, the sizable proportion of oil production and consumption variability accounted for by the own shocks, also in the medium- to long-term, would be consistent with the presence of geophysical constraint in the former case, and rigidities in oil consumption patterns, small, and declining over time, income and price elasticities, and low substitutability among energy sources, in the latter case.

Even stronger endogeneity is shown by both reserves and refinery margins in the short-term. For instance, the own shock accounts for 40% and 20% of fluctuations at the two- and five-year horizon, respectively, for both variables; macroeconomic and financial shocks jointly explain 50% of reserves fluctuations since the two-year horizon, while (other) oil market supply side shocks up to 20% in the medium- to long-term; similarly for refinery margins fluctuations, i.e. 20% and 40% (each) at the two-year horizon and in the medium- to long-term, respectively. The evidence is then consistent with the view that macro-financial developments may create incentives for oil producers in engaging in reserves discovery activities and investment, as well as that refinery margins are tuned according to the state of the business and financial cycle.

5.2 Oil inventories and futures market variables

Also inventories would be strongly endogenous, the own shock accounting for only 40% of fluctuations in the very short-term and 20% in the long-term. Both oil market supply side (12% in the medium- to long-term) and oil consumption (10% in the short-term) shocks, as well as macroeconomic (20% to 30%) and fundamental (20% to 25%) and non fundamental (4% to 7%) financial shocks, would sizably contribute to inventories fluctuations. In particular, the relevance of financial shocks for inventories fluctuations is consistent with the existence of a financial demand for oil, as the latter would influence the real oil price through inventories.

Both the Working's-T (WT) and futures basis (FB) would be fairly endogenous as well, the own shock accounting for about 50% of fluctuations in the very short-term in both cases; 40% and 20% in the short- and long-term, respectively, for WT; 20% and 15% for FB. Fundamental financial shocks would yield a sizable contribution to fluctuations in both variables in the very short-term (20%), while macroeconomic shocks in the short- to long-term (20% to 40% for WT; 30% for FB); a sizable contribution is also yield by oil market supply side shocks (up to 16%; long-term). Once accounted for the common fundamental information, residual fluctuations in FB and WT appear to be strongly unrelated; the proportion of FB variance explained by the WT shock is not larger than 0.3%, and the other way around. The two variables would therefore convey complementary information concerning the role of excess speculation in the oil futures market, justifying their joint inclusion in the model.

5.3 Real oil price and nominal oil price volatility

Strong endogeneity is also shown by the real oil price at any horizon, the own shock accounting for 20% of fluctuations in the very short-term, and for no more than 10% at any other horizon; similarly for nominal oil price volatility (30% in the very short-term; 15% in the long-term). Macroeconomic and fundamental financial shocks would jointly account for the bulk of real oil price fluctuations at any horizon (70% in the very short-term; 60% in the long-term), with macroeconomic shock yielding a larger contribution than financial shocks (up to 50% and 25%, respectively, short-term; 40% and 20%, respectively, medium- to long-term). The contribution of macroeconomic and fundamental financial shocks to nominal oil price volatility fluctuations is also sizable, and larger for financial than macroeconomic shocks in the long-term (15% in the short-term; 30% and 5%, respectively, in the long-term); macro-financial shocks would then jointly account for 25% of nominal oil price volatility fluctuations in the very short-term; 45% and 35% in the short- and long-term, respectively.

Among fundamental financial shocks, risk factors shocks (up to 30%; not reported) would be the main determinant of nominal oil price volatility fluctuations, while liquidity and interest rates shocks (up to 15%; not reported) would matter most for the real oil price; risk factors (10%; not reported) and portfolio (up to 10%) shocks would also yield a sizable contribution to real oil price fluctuations. Moreover, among macroeconomic shocks, aggregate demand (up to 20%; not reported), US trade deficit and productivity shocks (up to 14% each; not reported) would matter most for the real oil price, while labor supply shocks for nominal oil price volatility (up to 7%; not reported).

Also, non fundamental financial shocks would yield a larger contribution to real oil price fluctuations in the medium- to long-term (5%) than in the short-term, and the other way around for nominal oil price volatility (5% in the very short-term); a larger role for oil market supply side shocks is also found for nominal oil price volatility than the real oil price (15% to 30% and 5% to 10%, respectively); similarly for US$ exchange rate shocks (up to 10% and 5%, respectively) and inventory shocks (up to 5%, respectively); conversely, oil consumption shocks would more sizably contribute to real oil price than nominal oil price volatility fluctuations (up to 10% and 5%, respectively).

Finally, real oil price and nominal oil price volatility own shocks negligibly account for each other fluctuations (1%; not reported).

6 Impulse response analysis

Concerning the transmission mechanism of the various shocks within the oil market, the results of the impulse response analysis are reported in Figures 1-2 for the oil price and in Tables 2-4 for all variables, over selected horizons, as for the forecast error variance decomposition analysis. In all cases median cumulated responses have been computed with 90% significance bands.[36] In the tables significant figures at the 10% level, are shown in bold.

6.1 Oil market shocks

Oil market supply side shocks Firstly, a (unitary and permanent) positive *reserves* shock would lead to a sizable short-term contraction in the real oil price (-1%; Table 3, Panel C). A temporary negative effect can also be noted on the futures basis, strongly declining within two quarters (-1.9%, Table 4, Panel B), consistent with the market expecting lower real oil prices in the future. Both nominal oil price volatility (-0.75%, Table 4, Panel C) and excess speculation (Working's-T, -0.34%, Table 5, Panel A) would be permanently dampened.

Secondly, a *negative net production* shock (downward shift in the flow oil supply) would lead to a short-term increase in the real oil price (3.3%) and nominal oil price volatility (0.7%), yet to a long-term contraction in nominal oil price volatility (-1%). The futures basis also increases in the very short-term only (0.63%), consistent with expected higher oil prices and weaker fundamentals in the future. A permanent negative impact on excess speculation (Working's-T index) can finally be noted (-0.6%). Note also

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[36] Non cumulated responses are only reported for the futures basis and the stocks' liquidity and leverage factors.

that, in the expectation of future oil supply shortfalls, inventories (0.3%) and refinery margins (0.82%) are permanently increased, in order to smooth consumption.

Differently, a *positive net production* shock (upward shift in the flow oil supply) would lead to a contraction in the real oil price in the short-term (-1.9%), but to a permanent increase in nominal oil price volatility (1.3%). The futures basis increases in the short-term (1.1%), consistent with expected stronger future flow oil demand. Inventories and oil consumption are also increased in the short-term (0.18% and 0.09%, respectively), stimulated by the reduction in the real oil price. A transitory negative impact on excess speculation can finally be noted (-0.15%).

Thirdly, a positive *refinery margins* shock would lead to a permanent contraction in the real oil price, which is already sizable in the short-term (-2% within 2 quarters; -1.4% at the 10-year horizon), consistent with a shift in the production mix favoring (relatively less expensive) medium and heavy sour crudes. The futures basis then contracts at the outset (-1.1%), while excess speculation increases in the short-term (0.17%). The impact on nominal oil price volatility is also permanent and sizable (0.5%).

Oil market demand side shocks Fourthly, concerning the effects of oil consumption and inventories preferences shocks, a positive *oil consumption* shock would lead to a permanent increase in the real oil price (3.3%), yet dampening nominal oil price volatility (-0.39%). The futures basis increases in the very short-term (1.2%), consistent with the expectation of stronger demand also in the future, while excess speculation (Working's-T) in the short-term (0.13%). The shock also permanently increases oil production and refinery margins (0.14% and 0.28%), while inventories are drawn down in the short-term (-0.3%) in order to smooth consumption. Differently a positive *inventories* shock would lead to a permanent contraction in the real oil price (-2.3% in the short-term; -0.93% in the long-term), dampening nominal oil price volatility (-0.56%) and stimulating oil consumption in the short-term (0.07%). The futures price contracts less than the spot price in the short-term, fully adjusting in the medium- to long-term, and therefore leading to a temporary increase in the futures basis (1.3%); refinery margins would also permanently contract (-0.1%).

Other real oil price and nominal oil price volatility shocks Finally, a positive bidirectional linkage would relate the real oil price level and nominal oil price volatility, a positive *other real oil price* shock leading to a permanent increase in nominal oil price volatility (0.21%), as well as a positive *other nominal oil price volatility* shock leading to a permanent increase in the real oil price (1.1%). The level of the oil price then matters for nominal oil price uncertainty, the latter increasing with the level of the real oil price; also, a type of positive risk-return relationship can be found for the oil price, which is consistent with oil being traded as a financial asset.

Moreover, positive real oil price and nominal oil price shocks would lead to an increase in the futures price, smaller than for the spot price for the former shock and larger for the latter shock, in the short-term. Hence, a temporary contraction (-0.44%) and a temporary increase (0.3%) in the futures basis are observed, respectively; no long-term impact on the future basis is however left by both shocks. Yet, excess speculation is permanently increased by real oil price shock (Working's-T, 0.06%), while dampened in the short-term by the nominal oil price volatility shock (Working's-T, -0.14%). Finally, the real oil price shock would also lead to a short- to medium-term contraction in oil consumption (-0.03%) and a short-term drawing down in inventories (-0.05%) to smooth oil consumption; refinery margins permanently decrease (-0.05%), consistent with the contraction in oil demand.

6.2 Macroeconomic shocks

Businness cycle and productivity shocks Firstly, the evidence is consistent with the view that macroeconomic fundamentals determine the real oil price by shifting flow oil demand according to the state of the business cycle; in fact, positive *labor supply*, *aggregate demand*, and *labor demand*[37] shocks would all exercise a sizable, positive impact on the real oil price at various horizons.

The strongest effect is shown by the aggregate demand shock at all horizons, leading to real oil price overshooting (6.6% very short-term; 3.6% long-term); differently, the impact of the labor supply (employment) shock builds gradually over time (0.86% very short-term; 2.3% long-term), while the effects of the labor demand shock would fade away in the medium-term (2.13% very short-term; 0.63% medium-term). Coherently, oil consumption increases, particularly in the short-term (0.13%, 0.21% and 0.11%, respectively); moreover, inventories are drawn down (-0.30%) and refinery margins increased (0.14%), in order to smooth consumption.

An improvement in economic conditions would also lead to the expectation of a higher real oil price in the future, as revealed by the futures basis permanently increasing following the labor supply (0.3%) and demand (0.16%)

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[37] In the impulse response tables, figures correspond to the effects of a negative labor demand shock; signs should then be reversed in order to gauge the effects of a positive shock.

shocks, as well as the aggregate demand (0.32%; medium-term) shocks; excess speculation in the oil futures market would be dampened by the two former shocks (-0.23% and -0.26%), yet increased by the latter one (0.13%).

Secondly, a positive *productivity* shock would also increase oil consumption (0.2% very short-term; 0.15% long-term) and refinery margins (0.44% long-term). The negative impact on the real oil price (-3.8% very short-term; -2.1% long-term) may be explained through a mechanism involving financial oil demand, as the productivity shock would lead to a long-term liquidity contraction (-0.5%; not reported) and a long-term increase in the real short-term interest rate (0.11%; not reported), both determining a contraction in the real oil price (see below for details). The increase in refinery margins triggered by the shock might also contribute to the real oil price contraction.

Thirdly, in general, business cycle shocks would exercise a dampening effect on nominal oil price volatility, which is permanent for the labor demand (-0.46%) and productivity (-0.29%) shocks and transitory for the aggregate demand shock (-0.35%); differently, a destabilizing effect can be noted for the labor supply shock (0.48%).

Fourthly, the evidence is also consistent with the view that the oil supply is managed according to the state of the business cycle. In fact, positive labor supply (0.11%) and aggregate demand (0.17%) shocks would lead to an increase in oil production, i.e. to an upward shift in the flow oil supply function; yet, only aggregate demand shocks would leave permanent effects on oil production (0.12%).

Other macroeconomic shocks Fifthly, a worsening in global economic conditions, as signaled by positive *core inflation* (N), *fiscal stance* (G) and *US fiscal deficit* (Fd) shocks, would lead to a contraction in oil consumption and production, most sizable in the short-term (-0.13% and -0.02%, N; -0.05% and -0.18%, G; -0.14% and -0.09%, Fd), and to a permanent contraction in the real oil price (-1.7%, -1.8% and -1.2%, respectively); as a positive *US trade deficit* shock would lead to a long-term contraction in the real interest rate (-0.04%; not reported), its positive impact on the real oil price may then be explained through a mechanism related to financial oil demand (see below for details), as well as by the short-term contraction in refinery margins triggered by the shock (-0.08%). Finally, mixed transitory effects can be found for nominal oil price volatility, increasing following the US fiscal deficit (0.59%) and core inflation (0.12%) shocks, and contracting following the fiscal stance (-0.12%) and US trade deficit (-0.18%) shocks.

6.3 Financial shocks

Excess liquidity and interest rate shocks Firstly, a positive *excess liquidity* shock would lead to a permanent contraction in the real short-term interest rate (-0.07%; not reported) and a permanent increase in the real oil price (2.3%), a short-term increase in the oil futures basis (1.5%) and a short-term contraction in nominal oil price volatility (-0.21%); coherently, inventories permanently increase (0.22% in the short-term; 0.09% in the long-term) and refinery margins contract (-0.1%). A long-term dampening effect on excess speculation (Working's-T, -0.86%) and oil consumption (-0.07%) can also be noted.

The above linkage between excess liquidity, the real interest rate, inventories, and the real oil price is then fully consistent with various mechanisms implying the existence of a fundamental financial demand for oil; for instance, a contraction in the real interest rate might lead to a higher real oil price by lowering the cost of holding inventories for traders and slowing down the rate of extraction for producers, as well as through lower discounting of the expected future stream of convenience yields; also, some evidence of overshooting in the real oil price, reminding of the Dornbusch-type monetarist mechanism, can be noted: in fact, following the excess liquidity shock, the real oil price would overshoot its long-term value after one quarter (3%; not reported), then undershoot it within one-year (1.5%), to overshoot it again within two years (2.6%), finally stabilizing after five years (2.3%)[38]; moreover, excess liquidity may lead to an increase in the demand for oil as a financial asset through a portfolio rebalancing/diversification mechanism: following the excess liquidity shock real commodity prices increase (2.3% oil; 2.2% gold and 1.1% non energy commodities; not reported), while real stock and housing prices contract (-0.09% and -0.56%, respectively; not reported).

An inverse relationship between the real interest rate and the real oil price, can also be noted following a positive *risk-free rate* shock, leading to a permanent contraction in the real oil price (-0.67%), as well as in the futures price, the futures basis being only increased in the short-term (1%); consistent with Hotelling (1931)'s theory, an increase in oil production in the short- to medium-term can also be noted (0.03%), as well as a permanent increase in reserves (0.38%); while nominal oil price volatility is left unaffected, oil inventories (0.11%) and consumption increase (0.12%, short-term) in response to the lower real oil price.

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[38] Note that the above dynamics are not strictly comparable with what predicted by the monetarist mechanism, as the latter refers to the effect of a temporary increase in liquidity, while the identified liquidity shock is a permanent one.

Asset prices (portfolio) shocks Secondly, a similar pattern can be detected concerning the effects of the *speculative asset price* shocks; in fact, positive *real stock market*, *housing*, *non energy commodities* and *gold* price shocks would lead to a permanent increase in the real oil price (1.1%, 2.3%, 0.32% and 1.3%, respectively), the futures basis being also increased in the short-term (0.14%, 1.1%, 0.36% and 0.57%, respectively); an increase in excess speculation (Working's-T), following the real housing and stock market price shocks (0.06%, 0.11%), as well as a permanent building up of inventories, apart from the stock market shock (0.16%, 0.04% and 0.08%), can also be noted. The above interactions are then consistent with an asset price channel and the existence of a fundamental financial demand for oil. Interestingly, only the real gold price shock would lead to a permanent increase in nominal oil price volatility (0.21%).

Thirdly, a positive US$ exchange rate index shock (depreciation shock) would lead to a permanent increase in the real oil price (2.5%), nominal oil price volatility (1.1%), excess speculation (Working's-T, 0.27%), and in the futures basis (0.45%; short- to medium-term only). Refinery margins also permanently contract (-0.2%), while inventories, albeit drawn down in the short-term (-0.18%) to smooth consumption, do increase in the long-term (0.14%). The US$ depreciation shock might then lead to a higher real oil price by contracting refinery margins and stimulating excess speculation in the futures market.

Risk factors shock Fourthly, a worsening in economic and financial stability conditions, as measured by positive *risk aversion*, *value* and *leverage* factor shocks, and negative *size*, *stocks' liquidity*, *momentum* and *term spread*[39] shocks,[40] would lead to a contraction in the real oil price: in the short-term following the risk aversion and value factor shocks (-0.97% and -1.18%, respectively), as well as in the long-term following the size, momentum, stocks' liquidity, leverage and term spread shocks (-0.93%, -0.55%, -0.65%, -2.2%, -0.48%, respectively).

All the shocks would also lead to a reduction in the futures basis at various

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[39] In the impulse response tables, figures correspond to the effects of a positive term spread shock; signs should then be reversed in order to gauge the effects of a negative shock.

[40] During economic downturn, small firms are more strongly affected than large firms, investors shift from growth to value stocks (*flight to quality*), stock returns are in general negative, uncertainty and risk aversion increase, portfolio are rebalanced favoring (safer) bonds over stocks, credit and liquidity conditions worsen, monetary policy is accommodative; moreover, the higher is the leverage and the lower the resilience of the financial system.

horizons (-0.27% to -1.2%) and in excess financial speculation (Working's-T; -0.12% to -0.59%, apart from the leverage and term spread shocks).

The effects on oil price volatility and inventories are mixed. In fact, volatility would be dampened by the value, momentum, and stocks' liquidity shocks (-1.2%, -0.91%, -0.27%), yet stimulated by the risk aversion, size, leverage and term spread shocks (0.32%, 0.25%, 0.34%, 0.31%); also, inventories would be drawn down following risk aversion, momentum, leverage and term spread shocks (-0.1% to -0.37%), yet accumulated following size, value and stocks' liquidity shocks (0.08% to 0.3%).

Differently, a positive *fragility* shock would lead to a short-term increase in the real oil price (0.22%) and the futures basis (0.24%) and to a permanent increase in oil price volatility (0.09%).

Overall, the effects of risk factors shocks on the real oil price can be explained through a liquidity effect: in fact, excess liquidity would increase following the positive fragility shock (0.11%; not reported), therefore contributing to increasing the real oil price; also, following positive value and leverage shocks, as well as negative momentum and size shocks, excess liquidity would decrease (-0.49%, -0.31%, -0.14%, -0.72%; not reported), therefore leading to a contraction in the real oil price; differently, positive risk aversion and negative stocks' liquidity shocks would lead to an increase in liquidity (0.30%, 0.09%; not reported) and therefore in the real oil price. Moreover, the negative effect of the term spread shock on the real oil price can be related to decreased oil consumption (-0.11% short-term; -0.05% long-term), production (-0.07% short-term; -0.02% long-term) and inventories (-0.1%), as triggered by the shock, and therefore to flow oil demand and supply interactions, in the expectation of a worsening in economic conditions.

Oil futures market speculative shocks Following positive *Working's-T* and *futures basis* shocks the real oil price would increase 0.3% in the very short-term, and 0.6% and 2.4%, respectively, in the long-term; the impact on the futures basis is also positive, yet transitory for both shocks (0.08% and 4.4%, respectively); the impact on nominal oil price volatility would also be permanent, yet negative (-0.2% and -0.1%, respectively), pointing to a significant *liquidity effect* associated with non fundamental financial shocks in the oil futures market. Moreover, while a permanent accumulation of inventories can be noted following a positive Working's-T shock (0.2%), a contraction can be observed following a positive futures basis shock (-0.15%): the latter finding may be related to consumption smoothing as, following the sizable real oil price increase triggered by the futures basis shock, oil consumption contracts also in the long-term (-0.03%).

Interestingly, the futures basis shock would permanently and negatively affect also oil production (-0.03%) and refinery margins (-0.07%). Hence, non fundamental financial shocks may lead to a higher real oil price, also without affecting (above ground and offshore) inventories: this would entail a downward shift in the flow oil supply schedule, possibly in the expectation of a downward shift in flow oil demand, triggered by the higher real oil price, and a shift in the production mix in favor of (relatively more expensive) light crudes, still in the expectation of a future slow down in demand and less binding margins. The latter is also consistent with an *oil in the ground* type of policy, i.e. the underground accumulation of inventories by oil producers, by slowing down the extraction rate.

7 Historical decomposition: the oil price-macro-finance interface

In order to gauge the effects of various categories shocks on the level of the real oil price and nominal oil price volatility, as for the forecast error variance decomposition analysis, in Figures 3-4 the cumulative historical decomposition (net of base prediction) for the real oil price growth rate and nominal oil price volatility changes, over the period 1986:4 through 2010:3, is reported. To facilitate visual inspection, the initial value is set equal to zero in all cases and a spline smoother is also plotted in the graphs.

A shown in Figure 3, macroeconomic shocks were the major upward driver of the real oil price over the whole period investigated; financial shocks sizably contributed to increasing the real oil price since early 2000s as well, and even more since mid 2000s, fundamental dominating non fundamental financial shocks; inventories shocks and *other* real oil price shocks contributed as well, albeit at a smaller extent; similarly US$ exchange rate and oil market supply side shocks since early 2000s. Differently, the oil consumption preferences shock was a downward driver of the real oil price over the whole period investigated, consistent with a substitution pattern favoring other energy sources.

Moreover, as shown in Figure 4, oil market supply side shocks were the major upward driver of nominal oil price volatility; oil consumption and inventories shocks also yield a minor contribution to increasing nominal oil price volatility over the whole period considered, and similarly US$ exchange rate shocks since mid 2000s. Macroeconomic and fundamental financial shocks, as well as nominal oil price volatility shocks, contributed to stabilizing the nominal oil price over the whole period investigated, as well as non fundamental financial shocks since mid 2000s. While the stabilizing contribution of financial shocks can be understood in terms of a liquidity effect, the Great Moderation phenomenon and the progressive disinflation achieved by improved US monetary policy management over the period considered may explain the dampening effect of macroeconomic shocks on nominal oil price fluctuations. Finally, the smaller contribution of oil market supply side shocks to real oil price fluctuations since early 2000s (Figure 3), yet the positive contribution to nominal oil price volatility (Figure 4), may be understood as a US CPI price index effect.[41]

Moreover, in Figure 5 and 6 the decomposition of the financial component for both variables, relatively to the sub categories of liquidity and interest rate shocks (MP: excess liquidity, risk-free rate, term spread), portfolio allocation shocks (PA: real housing prices, real non-energy commodity prices, real stock prices, real gold price) and risk factors shocks (RF: risk aversion, size, value, momentum, stocks' liquidity and leverage factors, economic and financial fragility index) is plotted. In the latter plots, the non fundamental and fundamental financial components are also contrasted for both series.

As shown in Figure 5, among the fundamental financial shocks, portfolio allocation shocks were the main upward driver of the real oil price, particularly since mid 2000s; also liquidity and interest rate shocks contributed to increasing the real oil price, particularly over the 1990s and since mid 2000s; while risk factor shocks, in general, contributed to decreasing the real oil price over the sample investigated, a sizable positive impact can however be noted in 2006 and 2007.

Also, as shown in Figure 6, liquidity and interest rate shocks contributed to decreasing nominal oil price volatility over the sample investigated; differently, the evidence for portfolio allocation and risk factors shocks is not clear-cut.

Risk factors shocks were also the main determinant of the fundamental financial component for both the real oil price and nominal oil price volatility; also liquidity/interest rate shocks and portfolio allocation shocks sizably contributed to determining the fundamental financial component, and the former more than the latter for the real oil price. Finally, the dominance of the fundamental over the non fundamental financial component is a clear-cut finding for both the real oil price and nominal oil price volatility.

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[41] If o is the log real oil price and p log US CPI, the variance of the log nominal oil price $(p+o)$ is $V_{p+o} = V_p + V_o + 2Cov(p,o)$. Hence, when V_o contracts, V_{p+o} may increase, decrease or remain unchanged according to the changes occurring in V_p and $Cov(p,o)$.

The third oil price shock episode The 2007-2009 oil price episode surely stands out for both the very high nominal oil price level (US$ 140, July 2008), comparable in real terms with the second oil price shock, and volatility (100 US$ drop within 5 months; US$ 40, December 2008). As reported in Table 5, over the period 2004:1 through 2010:3, the real oil price increased 65%; of the latter, 33% is related to fundamental financial shocks and 11% to non fundamental financial shocks; macroeconomic shocks contributed with a 5% increase, while inventories (3%), oil market supply side (3%) and idiosyncratic (*other*) real oil price and consumption (5.5% each) shocks jointly accounted for an additional 17% increase; finally, US$ exchange rate shocks (-1%) contributed to slightly dampening the real oil price increase. Over the same period, nominal oil price volatility cumulatively increased 1%, as the result of fundamental (-4%) and non fundamental (-3%) financial shocks, macroeconomic (-4%), oil consumption (-2%) and other nominal oil price volatility (-4%) shocks dampening the destabilizing effects of oil market supply side (14%), inventories (1%), and US$ exchange rate (2%) shocks.

Despite the large contribution of financial shocks to the real oil price increase since 2004, it would be inaccurate describing the *third oil price shock* as a purely “financial” episode. As shown in Table 5 (Figure 7), the 2007-2009 episode is a macro-finance episode, with macroeconomic factors actually playing a larger role than financial factors. In fact, the 2007(2) through 2008 (2) real oil price run up (68%) is largely accounted for by macroeconomic shocks. Indeed macroeconomic shock accounted for 6% of the 9% increase in 2007(2), 7% of the 15% increase in 2007(3), 14% of the 17% increase in 2007(4), 14% of the 6% increase in 2008(1) and 17% of the 21% increase in 2008(2), i.e. 58% of the 68% overall real oil price increase. The contribution of fundamental and non fundamental financial shocks to the real oil price increase was sizable (6%) only in 2007(4), actually contributing to decreasing the real oil price in 2007(2) and 2008(1) (-4% and -3%, respectively). Moreover, while the -7% real oil price drop in 2008(3) is accounted for by oil market supply side (-4%) and real oil price idiosyncratic shocks (-7%), the -67% contraction in 2008(4) is accounted for by both macroeconomic (-40%) and financial (-14%) shocks, with the former largely dominating the latter; similarly for the -31% real oil price contraction in 2009(1) (-26% and -7%, respectively). Yet, over the 2009(2) through 2009(4) period, macroeconomic (21%) and financial (20%) shocks equally contributed to the 54% real oil price increase.

7.1 Other episodes

The sample investigated covers some additional relevant real oil price episodes, namely the first Persian Gulf War (1990-1991), the East Asia crisis and recovery (1997-2000), the Venezuelan strike and the second Persian Gulf War (2002-2003).

Interestingly, a sizable role for macro-financial shocks can be found for all the above mentioned episodes.

The first Persian Gulf War As shown in Figure 8 and Table 6, following the Iraqi invasion of Kuwait in August 1990, an abrupt and large increase in the real oil price occurred in 1990:3 (38%), followed by an additional sizable increase in 1990:4 (17%); the oil price crisis was however already resolved in 1991:1 (-40%), as Saudi Arabia used its spare capacity to restore global oil production. Oil market supply side shocks largely contributed to real oil price dynamics over the selected period, i.e. 10% in 1990:3, 16% in 1990:4, -12% in 1991:1 and -9% in 1991:2, as well as to oil price volatility (10% in 1990:3); yet, macro-financial shocks also played a relevant role for the quarters over which the largest swing can be noted, i.e. 1990:3 and 1991:1. In particular, macro-financial shocks accounted for a 22% increase in 1990:3 and a -24% contraction in 1991:1, hence dominating the contribution of oil market supply side shocks in both quarters; also, while financial shocks (17%) dominated macroeconomic shocks (5%) in 1990(3), macroeconomic (-11%) and financial (-12%) shocks yield a similar contribution in 1991(1). Moreover, while the contribution of macroeconomic shocks was negligible, financial shocks contributed with a 4% increase in 1991(2); hence, only in 1990(4) and 1991(2) the contribution of oil market supply side shocks was dominant. Finally, among financial shocks, fundamental shocks always dominated non fundamental shocks over the period investigated.

Overall, over the period 1990:3-1991:2, the real oil price featured a 10% increase; of the latter, 5% can be associated with oil market supply side shocks and 12% with fundamental financial shocks; also, -9% is accounted for by macroeconomic shocks, while non fundamental financial shocks contributed with a -4% contraction. Moreover, over the same period, nominal oil price volatility featured an 11% increase; of the latter, 4% can be related to oil market supply side shocks, 5% to fundamental financial shocks, and 1% (each) to macroeconomic and non fundamental financial shocks. Hence, while the 1990-1991 episode can be understood as an oil market supply side episode, the sizable contribution given by macro-financial shocks should not be neglected. Finally, financial shocks contributed to increasing both the real oil price level and nominal oil price volatility during the first Persian Gulf

War episode.

East Asia crisis and recovery As shown in Figure 9 and Table 6, the -23% real oil price contraction in 1998:1 is largely explained by fundamental financial shocks (-13%), non fundamental financial (-1.4%), US$ exchange rate and oil market supply side (-3% each) shocks also contributing, consistent with the East Asia financial crisis, started in summer 1997, exercising its effects on the global economy; sizable real oil price contractions can be noted throughout 1998 (-23%, 1998:2 through 1998:4), largely related to macroeconomic (-4%), oil supply side (-15%) and non fundamental financial (6%) shocks. A sizable role for fundamental financial shocks can be noted in 1998(3) (16%) and 1998(4) (-16%), also contributing with a 2% increase in 1998(2). Finally, the 3% nominal oil price volatility increase in 1998 can be largely related to oil market supply side and macroeconomic shocks.

As recovery from the financial crisis gained pace, steady real oil price appreciation can be noted in 1999, i.e. a cumulative 53% increase, largely accounted for by oil market supply side (30%), macroeconomic (42%) and fundamental financial (-15%) shocks; also, the moderate increase in oil price volatility in 1999 (2.5%) is mostly related to fundamental financial shocks (4.9%), dampened by macroeconomic shocks (-3.1%).

Overall, over the period 1998:1 through 1999:4, the real oil price featured a 15% increase; of the latter, 12% can be associated with oil market supply side shocks, 38% with macroeconomic shocks and 3% with non fundamental financial shocks; fundamental financial and exchange rate shocks contributed to dampening the real oil price increase (-26% and -7%, respectively). Moreover, of the 6% cumulative increase in nominal oil price volatility over the same period, 7% can be related to oil market supply side shocks, 6% to fundamental financial shocks, and 1% to non fundamental financial shocks; differently, macroeconomic and exchange rate shocks contributed to dampening nominal oil price volatility (-1% and -2%, respectively). Hence, while the 1998-1999 episode is largely a macro-financial episode, the sizable contribution of oil market supply side shocks should not be neglected. Also, financial shocks contributed to decreasing the real oil price level, yet to increasing nominal oil price volatility during the East Asia crisis episode.

Venezuelan strike and second Persian Gulf War Between December 2002 and January 2003 a strike lead to a sizable contraction in Venezuelan oil supply. Then, with the US intervention in Irack, in April 2003 a sizable contraction in Iraqi oil supply was also scored. However, global oil supply did not seem to drop significantly following the events (Hamilton, 2011a).

As shown in Figure 10 and Table 6, oil market supply side shocks did not contribute sizably to oil price determination in 2002:4; of the -1% contraction, oil market supply side shocks contributed with -2%, with additional -5% and -4% yield by macroeconomic and fundamental financial shocks, respectively; differently, inventories, non fundamental financial and exchange rate shocks contributed with a 2% increase each. Also oil price volatility (-2%) was not sizably affected by the Venezuelan strike, the only destabilizing effect having been exercised by macroeconomic shocks (3%).

Oil market supply side conditions did not contribute also to the 18% oil price increase in 2003:1 (-2%), mostly driven by oil consumption (4%) and fundamental financial shocks (16%); the 3.3% volatility increase occurring 2003:1 can only be partially related to oil market supply side shocks (1%) as well.

The oil price episode was already resolved in 2003:2, as the real oil price dropped -17%, with a small increase in volatility (2%). Oil market supply side and US$ exchange rate shocks contributed with a 5% and 3% increase in the real oil price and a 1% increase in nominal oil price volatility (each), respectively; the real oil price contraction can be associated with macroeconomic (-14%) and financial shocks, both fundamental (-6%) and non fundamental (-3%).

Overall, over the period 2002:4 through 2003:3, the real oil price featured a 3% increase; of the latter, 7% can be associated with oil market supply side shocks, 8% with US$ exchange rate shocks and 4% with non fundamental financial shocks; differently, fundamental financial and macroeconomic shocks contributed to dampening the real oil price increase (-6% and -17%, respectively). Also, of the 2% volatility increase, 2% can be related to oil market supply side shocks, 3% to macroeconomic shocks, and 2% to exchange rate shocks; differently, financial shocks, fundamental (-2%) and non fundamental (-1%), contributed to dampening nominal oil price volatility. Hence, while sizable contributions were provided by oil market supply side shocks during the 2002-2003 oil price episode, also the latter was however largely macro-finance driven. Finally, financial shocks contributed to decreasing both the oil price and its volatility over the second Persian Gulf War episode.

8 Conclusions

What is the role of financial speculation in the determination of the real oil price? In the light of the contrasting empirical evidence available in the literature, the current paper then aims at assessing the contribution of macro-financial interactions to recent oil price dynamics. The paper is innovative under different perspectives. Firstly, differently from recent empirical contributions, based on small scale dynamic models, large scale modelling of the global oil market macro-finance interface is performed. In addition to macro-financial factors related to the global business and financial cycle, risk factors, proxying for expectations about future fundamentals and economic/financial fragility conditions, have also been considered in the information set.

To our knowledge this study is the first attempt in the literature to exploit the information on expected future fundamentals contained in risk factors, within the framework of a macroeconometric model, and to the purpose of modelling real oil price dynamics. While Kilian and Murphy (2010), by including inventories in their model, do allow for a financial oil demand component and, indirectly, for the effect of future fundamentals on oil demand, our contribution, by conditioning on risk factors, is the first attempt at *directly* measuring their effects. By including measures of excess speculation, our study also aims at disentangling the fundamental and non fundamental components of financial oil demand, which are left indistinct in Kilian and Murphy (2010). We do find that without a careful description of the *financial side*, *shocks* and *transmission mechanisms*, important to the understanding of the oil market, would go neglected.

Secondly, the proposed modelling approach leads not only to confirm previous evidence, but also to important new insights.

For instance, we find that, at least since the mid-1980s, the real oil price has been strongly endogenous and mainly demand driven, with both macroeconomic and financial shocks sizably contributing to oil price dynamics, consistent with the relevance of both flow and financial oil demand components. While, macroeconomic shocks were the major upward driver of the real oil price over the whole period investigated, financial shocks sizably contributed to increasing the real oil price since early 2000s as well, and even more since mid 2000s; similarly oil market supply side shocks since early 2000s, albeit at a much smaller extent than macroeconomic shocks. Macroeconomic and fundamental financial shocks also contributed to stabilizing nominal oil price volatility over the whole period investigated, and non fundamental financial shocks as well since mid 2000s; differently, oil market supply side shocks have been the major upward driver of nominal oil price volatility.

Moreover, of the 65% real oil price increase over the period 2004:1 through 2010:3, 33% is related to fundamental financial shocks and 11% to non fundamental financial shocks; macroeconomic and oil market supply side shocks contributed with a 5% and 3% increase, respectively. Yet, despite the large contribution of financial shocks, it would be inaccurate describing the third oil price shock as a purely *financial* episode. The 2007-2009 episode is a *macro-finance* episode: macroeconomic shocks accounted for 58% of the 68%

real oil price run up over the 2007(2)-2008 (2) period, while the contribution of financial shocks was sizable (6%) only in 2007(4); moreover, the -67% contraction in 2008(4) and the -31% contraction in 2009(1) are largely accounted for by macroeconomic shocks (-40% and -26%), with financial shocks (-14% and -7%) also sizably contributing; only over the 2009(2) through 2009(4) period macroeconomic (21%) and financial (20%) shocks equally accounted for the 54% real oil price increase.

A macro-finance perspective is also useful to understand the other oil price episodes since the mid-1980s: even for the first Persian Gulf War episode, only 5%, out of the 10% real oil price increase between 1990:3 through 1991:2, can actually be associated with oil market supply side shocks, fundamental financial shocks having contributed with a 12% increase, macroeconomic shocks with a -9% contraction, and non fundamental financial shocks with an additional -4% contraction.

Overall, while we provide support to the demand view of the real oil price determination, we do also find a larger role for financial shocks than previously noted in the literature.

We ascribe the above important findings to the careful modelling of the macro-finance interface undertaken in this study. In a broader perspective, recent dramatic macroeconomic episodes have reminded of the somewhat forgotten macro-finance interface in macroeconomic analysis; the paper also contributes to this issue, pointing to the importance of better integrating financial shocks and transmission mechanisms within the modelling of the oil price and macroeconomic dynamics. Our contribution then provides empirical facts on the oil market-macro-finance interface, as well as inferential procedures suitable for more general applications.

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Table 1: forecast error variance decomposition, contributions of subsets of structural shock

	World oil reserves								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
2	6.8	0.7	0.3	13.2	0.0	6.1	0.6	0.2	72.1
4	9.3	0.4	0.1	23.9	0.7	9.9	0.3	0.1	55.4
6	9.8	0.9	0.1	30.0	1.1	12.7	0.2	0.1	45.1
8	10.8	1.7	0.1	32.8	1.4	14.5	0.2	0.2	38.3
12	13.1	3.0	0.2	34.1	1.2	17.0	0.1	0.4	30.9
20	16.7	3.7	0.3	34.2	0.8	17.5	0.1	0.6	26.2
40	21.2	3.7	0.2	33.8	0.5	15.4	0.1	0.6	24.5

	Oil net production decreases								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.0
2	3.4	0.6	0.5	15.3	0.8	7.7	1.0	0.0	70.7
4	2.7	0.6	0.4	21.9	0.5	14.3	0.9	0.1	58.6
6	2.1	0.8	0.4	22.8	0.5	17.7	1.2	0.1	54.5
8	1.8	0.8	0.4	22.6	0.4	17.6	1.7	0.2	54.4
12	1.6	1.2	0.5	22.8	0.4	17.9	1.9	0.2	53.5
20	1.3	1.1	0.6	23.4	0.4	17.9	2.2	0.3	52.7
40	1.2	0.8	0.8	23.6	0.3	17.5	2.7	0.4	52.7

	Oil net production increases								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.9
2	0.9	0.4	0.0	3.8	1.0	3.2	0.1	0.0	90.6
4	1.0	0.9	0.6	8.6	1.1	11.8	0.6	0.1	75.3
6	2.5	2.2	1.3	11.1	1.2	19.1	0.8	0.2	61.6
8	3.3	3.7	1.5	11.7	1.1	24.5	0.7	0.2	53.3
12	3.3	5.6	1.3	12.4	1.0	28.8	0.6	0.1	46.8
20	2.9	6.5	1.4	12.1	0.9	30.2	0.5	0.1	45.4
40	2.5	6.7	1.8	11.3	1.0	30.1	0.6	0.1	45.9

	Refinery margins								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.1
2	2.2	3.9	0.0	7.1	0.1	6.5	0.2	0.3	79.6
4	7.6	12.8	0.1	8.8	0.3	13.3	0.2	0.2	56.6
6	13.8	12.5	0.2	10.2	0.9	16.9	0.1	0.2	45.0
8	19.0	10.6	0.3	13.4	1.3	17.0	0.2	0.2	38.0
12	26.0	8.4	0.3	17.3	1.4	17.0	0.1	0.2	29.2
20	31.1	5.2	0.4	20.5	1.3	17.9	0.2	0.1	23.3
40	36.1	3.8	0.4	22.1	1.2	17.2	0.2	0.1	19.0

	Oil consumption								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	3.7	82.6	0.0	13.7	0.0	0.0	0.0	0.0	82.6
2	6.3	66.0	0.7	19.3	0.1	7.3	0.2	0.1	66.0
4	5.8	58.8	0.5	22.0	0.3	12.3	0.3	0.1	58.8
6	6.0	56.3	0.5	22.0	0.6	14.3	0.3	0.1	56.3
8	6.0	55.9	0.5	21.1	0.7	15.4	0.3	0.1	55.9
12	5.8	57.0	0.4	19.4	1.0	16.0	0.3	0.1	57.0
20	6.0	60.1	0.3	17.3	1.3	14.5	0.3	0.1	60.1
40	6.5	63.1	0.2	15.7	1.6	12.4	0.4	0.1	63.1

	Inventories								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	2.1	5.7	37.0	21.2	4.7	25.0	4.2	0.0	37.0
2	1.8	10.2	31.2	28.9	3.1	21.2	3.4	0.1	31.2
4	3.0	9.7	31.9	26.7	2.1	22.6	3.9	0.1	31.9
6	4.5	8.5	30.8	27.4	1.6	23.0	4.1	0.1	30.8
8	4.9	8.3	29.0	28.8	1.6	22.4	4.9	0.1	29.0
12	7.9	6.1	25.5	30.4	2.1	21.9	5.9	0.1	25.5
20	10.2	3.7	23.3	31.9	2.3	22.2	6.2	0.1	23.3
40	12.4	2.0	22.2	32.8	2.2	21.7	6.6	0.1	22.2

	Oil price								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	7.9	0.0	2.3	44.2	1.9	25.7	0.3	17.7	17.7
2	10.9	3.8	2.5	49.4	3.2	17.2	3.2	9.9	9.9
4	9.1	4.7	3.1	46.9	4.3	17.7	3.3	10.8	10.8
6	7.7	5.8	3.2	43.8	4.6	19.9	3.7	11.3	11.3
8	6.8	7.2	2.8	41.8	5.0	21.0	4.4	10.9	10.9
12	6.0	8.4	2.1	41.0	5.1	22.2	5.0	10.1	10.1
20	5.1	9.9	1.7	39.4	5.4	22.8	5.7	10.0	10.0
40	4.3	10.8	1.4	38.6	5.9	22.9	6.2	9.9	9.9

	Oil price volatility								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	20.8	4.6	5.9	10.7	7.3	13.6	6.4	1.5	29.2
2	15.9	2.8	5.3	16.0	3.8	27.5	3.3	0.9	24.6
4	20.0	2.1	4.3	11.9	5.4	34.0	2.2	0.5	19.6
6	22.3	1.9	3.9	9.7	7.3	34.7	1.9	0.5	17.8
8	24.0	1.9	3.7	8.9	8.3	33.7	1.7	0.4	17.5
12	26.7	1.8	3.5	7.8	8.4	32.2	1.4	0.4	17.6
20	29.3	1.7	3.4	6.4	9.8	31.2	1.1	0.4	16.7
40	31.6	1.6	3.3	5.7	10.8	30.1	0.8	0.4	15.6

	Working’s T index								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	5.5	0.2	0.0	14.8	7.0	19.6	0.0	0.0	52.9
2	5.4	2.4	0.3	21.5	2.9	21.2	0.3	0.3	45.8
4	5.4	2.1	0.2	24.2	3.0	22.5	0.2	0.2	42.1
6	5.5	1.5	0.1	27.8	3.1	23.2	0.1	0.2	38.5
8	5.6	1.3	0.1	30.2	3.0	22.5	0.1	0.1	36.9
12	6.5	1.0	0.1	34.0	2.8	21.6	0.1	0.1	33.8
20	8.6	0.5	0.2	39.5	2.6	20.3	0.0	0.1	28.2
40	12.0	0.3	0.3	42.7	2.6	19.0	0.0	0.1	22.9

	Futures basis								
	SUP	C	INV	MAC	X	FIN	SPC	OP	OWN
0	5.7	3.7	0.0	17.2	0.0	19.0	0.2	0.0	54.2
2	13.3	7.5	4.9	32.2	0.8	18.8	0.3	1.2	21.1
4	17.1	7.2	4.9	32.8	0.7	19.1	0.3	1.1	16.8
6	16.9	6.7	4.5	32.5	0.8	22.4	0.3	1.0	14.9
8	17.0	6.7	4.3	33.0	1.0	22.4	0.3	1.0	14.3
12	17.5	6.6	4.3	32.2	1.7	22.9	0.3	1.0	13.5
20	16.9	6.7	4.1	32.1	1.9	24.1	0.3	1.0	13.0
40	16.9	6.7	4.1	32.0	1.9	24.2	0.3	1.0	12.9

The table reports the forecast error variance decomposition for world oil reserves, net oil production changes, refinery margins, oil consumption, inventories, the real oil price, the nominal oil price volatility, the Working’s T index, and the futures basis, at selected horizons (impact (0) and 2 to 40 quarters), relatively to subsets of structural shocks (net of the contribution of the own shock) : oil supply shocks (SUP, reserves, net production changes, refinery margins, oil consumption shocks (C), inventories shocks (INV), macroeconomic shocks (MAC: labor supply and demand, aggregate demand, fiscal stance, US fiscal and trade deficit, core inflation, productivity), US$ exchange rate index shocks (X), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, real housing prices, risk aversion, size, value, momentum, liquidity and leverage factors, real commodity prices, real stock prices, economic and financial fragility index, nominal oil price volatility), financial speculation (SPC: Working-T index, futures basis), the real oil price (OP), and the own shock (OWN). For instance, for world oil reserves, the SUP subset is net of the contribution of the reserves own shock, which is reported under the OWN category.

Table 2: impulse response analysis, world oil reserves, production and refineries margins; responses to each structural shock

Panel A: world oil reserves

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	**0.39**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	**0.79**	**0.20**	**0.21**	**0.10**	**0.07**	**-0.08**	0.03	-0.02	**0.09**	**-0.21**	**0.05**	**0.32**	**-0.09**	**0.04**	**-0.02**	0.00	**0.16**
4	**1.00**	**0.38**	**0.25**	**0.17**	**0.08**	**-0.24**	0.00	**-0.08**	**0.28**	**-0.44**	0.03	**0.59**	**0.08**	0.05	**0.09**	**0.06**	**0.36**
6	**1.20**	**0.55**	**0.22**	**0.24**	0.07	**-0.38**	0.03	**-0.15**	**0.42**	**-0.64**	0.00	**0.80**	**0.26**	0.01	**0.18**	**0.13**	**0.53**
8	**1.29**	**0.79**	0.14	**0.26**	0.13	**-0.52**	0.09	**-0.26**	**0.51**	**-0.75**	-0.03	**0.92**	**0.42**	-0.01	**0.28**	**0.18**	**0.66**
12	**1.43**	**1.10**	0.00	**0.26**	0.13	**-0.61**	0.05	**-0.38**	**0.66**	**-0.88**	-0.06	**1.12**	**0.59**	-0.07	**0.43**	**0.26**	**0.77**
20	**1.53**	**1.44**	-0.19	**0.27**	-0.09	**-0.66**	0.02	**-0.33**	**0.77**	**-0.87**	0.02	**1.21**	**0.64**	-0.11	**0.41**	**0.23**	**0.67**
40	**1.66**	**1.65**	-0.29	**0.35**	-0.19	**-0.70**	0.03	**-0.31**	**0.83**	**-0.92**	0.08	**1.34**	**0.66**	-0.14	**0.38**	**0.21**	**0.66**

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	0.02	**0.04**	**-0.15**	0.01	**0.06**	0.00	**-0.03**	**-0.02**	**-0.07**	**-0.05**	**0.04**	**0.13**	**-0.03**	**-0.04**	**-0.06**	**0.01**	
4	**0.16**	**0.21**	**-0.17**	-0.01	**0.08**	**-0.14**	**-0.10**	0.01	**-0.07**	-0.02	**-0.03**	**0.16**	-0.02	**-0.06**	0.02	**0.03**	
6	**0.24**	**0.35**	**-0.11**	0.01	**0.05**	**-0.26**	**-0.18**	0.02	**-0.06**	0.01	**-0.09**	**0.15**	0.01	**-0.08**	**0.06**	**0.03**	
8	**0.31**	**0.43**	-0.03	0.07	0.01	**-0.36**	**-0.24**	0.03	-0.06	0.07	**-0.15**	**0.12**	0.04	**-0.07**	**0.12**	**0.03**	
12	**0.26**	**0.56**	0.08	**0.21**	**-0.09**	**-0.50**	**-0.34**	0.02	-0.04	**0.15**	**-0.23**	0.05	0.06	**-0.08**	**0.15**	0.03	
20	0.17	**0.56**	-0.05	**0.37**	**-0.11**	**-0.56**	**-0.30**	0.01	-0.04	**0.16**	**-0.26**	-0.05	0.07	**-0.15**	0.12	0.01	
40	0.13	**0.53**	-0.15	**0.44**	-0.11	**-0.57**	**-0.27**	0.01	-0.07	0.15	**-0.27**	-0.08	0.07	**-0.19**	0.08	-0.01	

Panel B: oil production

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	**-0.02**	**-0.21**	**0.40**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	**-0.03**	**-0.17**	**0.41**	**0.00**	**0.07**	-0.01	**0.03**	**-0.03**	**-0.09**	0.00	**0.01**	**-0.04**	**0.03**	0.00	**0.01**	**-0.05**	0.01
4	**0.03**	**-0.15**	**0.42**	0.02	**0.07**	-0.01	**0.17**	**-0.03**	**-0.05**	0.00	0.00	**-0.08**	**0.07**	**-0.04**	0.00	**0.02**	**0.07**
6	**0.12**	**-0.15**	**0.41**	**0.05**	**0.11**	0.00	**0.17**	**-0.04**	**0.04**	0.00	**-0.02**	**-0.03**	**0.14**	**-0.06**	0.02	**0.06**	**0.12**
8	**0.17**	**-0.15**	**0.42**	0.03	**0.08**	-0.01	**0.14**	**-0.05**	**0.06**	0.00	**-0.02**	**0.04**	**0.19**	**-0.05**	**0.03**	**0.07**	**0.12**
12	**0.08**	**-0.13**	**0.36**	0.01	**0.05**	**-0.01**	**0.12**	**-0.03**	**0.03**	0.01	**-0.01**	**-0.02**	**0.19**	**-0.05**	**0.03**	**0.06**	**0.09**
20	**0.05**	**-0.14**	**0.35**	0.02	0.01	0.00	**0.11**	**-0.02**	**0.01**	**0.05**	0.00	**-0.07**	**0.13**	**-0.05**	**-0.03**	**0.01**	**0.02**
40	**0.06**	**-0.13**	**0.36**	0.02	0.03	0.00	**0.12**	**-0.02**	**0.01**	0.04	-0.01	**-0.04**	**0.14**	**-0.05**	**-0.02**	**0.02**	**0.04**

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	**0.02**	**-0.02**	**0.04**	**0.00**	0.00	**-0.01**	0.01	0.00	**-0.02**	0.00	**0.01**	**-0.02**	0.00	**0.02**	0.00	**0.01**	
4	**0.07**	**0.09**	**0.15**	**0.00**	**-0.04**	0.00	**-0.01**	0.00	**-0.02**	0.00	**0.03**	**0.04**	0.00	**0.01**	**-0.02**	**0.01**	
6	**0.06**	**0.20**	**0.14**	**0.00**	**-0.03**	0.00	**-0.02**	0.00	**-0.04**	-0.01	**0.03**	**0.10**	0.00	**0.02**	**-0.03**	**0.03**	
8	**0.07**	**0.31**	**0.12**	**0.00**	**-0.02**	**-0.02**	**-0.02**	0.01	**-0.04**	-0.02	0.01	**0.09**	0.00	0.01	**-0.02**	**0.03**	
12	**0.05**	**0.26**	**0.13**	**0.00**	**-0.02**	**-0.01**	**-0.01**	0.01	**-0.03**	-0.01	0.00	**0.02**	0.00	0.01	**-0.02**	**0.02**	
20	**0.04**	**0.18**	**0.07**	**0.00**	**-0.02**	**0.00**	0.00	0.01	**-0.03**	-0.02	**0.01**	**0.02**	0.00	0.00	**-0.03**	**0.01**	
40	**0.05**	**0.20**	**0.09**	**0.00**	**-0.02**	**-0.01**	0.00	0.01	**-0.03**	-0.02	**0.01**	**0.03**	0.00	0.00	**-0.03**	**0.02**	

Panel B: refinery margins

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	-0.01	**0.02**	**0.02**	**0.32**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	**0.09**	0.03	0.01	**0.43**	**-0.05**	0.01	**0.09**	**-0.04**	**-0.12**	**-0.06**	**-0.03**	**0.02**	**0.15**	**-0.09**	0.01	-0.02	**0.05**
4	**0.18**	**0.18**	**-0.04**	**0.40**	**-0.08**	0.01	**0.14**	**-0.08**	**-0.06**	-0.04	0.01	**0.08**	**0.29**	**-0.16**	**0.04**	0.01	**0.04**
6	**0.25**	**0.26**	**-0.09**	**0.46**	**-0.17**	-0.01	**0.09**	**-0.10**	**0.08**	**-0.08**	0.00	**0.18**	**0.26**	**-0.24**	**0.04**	**0.06**	0.03
8	**0.33**	**0.36**	**-0.14**	**0.50**	**-0.29**	0.01	0.04	**-0.07**	**0.12**	-0.05	0.00	**0.28**	**0.28**	**-0.24**	0.02	**0.04**	-0.01
12	**0.32**	**0.54**	**-0.27**	**0.54**	**-0.45**	-0.03	0.06	0.03	**0.14**	-0.02	**0.10**	**0.24**	**0.27**	**-0.24**	**-0.05**	-0.02	**-0.11**
20	**0.42**	**0.65**	**-0.35**	**0.64**	**-0.56**	-0.04	0.07	**0.10**	**0.17**	-0.04	**0.17**	**0.32**	**0.24**	**-0.26**	**-0.12**	**-0.07**	**-0.15**
40	**0.53**	**0.82**	**-0.43**	**0.68**	**-0.61**	-0.08	0.07	0.08	**0.24**	-0.09	**0.19**	**0.44**	**0.28**	**-0.29**	**-0.10**	-0.07	**-0.13**

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	0.02	-0.02	**0.06**	**0.03**	**-0.05**	**-0.04**	**-0.03**	**0.03**	-0.01	0.00	**-0.03**	**-0.07**	**0.04**	0.00	0.00	**-0.03**	
4	**-0.05**	0.03	**0.11**	**0.11**	**-0.12**	**-0.03**	**-0.09**	0.01	0.01	**-0.04**	**-0.02**	**-0.09**	**0.03**	0.00	**-0.06**	**-0.04**	
6	**-0.12**	**0.09**	**0.08**	**0.14**	**-0.11**	**-0.05**	**-0.08**	0.00	**-0.03**	**-0.05**	**-0.03**	**-0.07**	-0.01	**-0.04**	**-0.09**	**-0.03**	
8	**-0.14**	**0.14**	**-0.07**	**0.17**	**-0.08**	**-0.11**	**-0.07**	0.01	**-0.04**	**-0.06**	**-0.04**	**-0.10**	-0.02	**-0.09**	**-0.10**	**-0.04**	
12	**-0.15**	0.04	**-0.18**	**0.24**	**-0.08**	**-0.10**	0.01	0.01	**-0.03**	**-0.07**	**-0.05**	**-0.19**	0.01	**-0.13**	**-0.11**	**-0.06**	
20	**-0.16**	-0.04	**-0.32**	**0.27**	-0.04	**-0.09**	**0.08**	0.03	**-0.06**	**-0.11**	**-0.03**	**-0.20**	0.01	**-0.18**	**-0.15**	**-0.08**	
40	**-0.20**	-0.02	**-0.36**	**0.34**	**-0.06**	**-0.12**	0.07	0.03	**-0.07**	**-0.10**	**-0.05**	**-0.23**	0.01	**-0.20**	**-0.16**	**-0.09**	

The table reports impulse responses for oil reserves (Panel A), oil production (Panel B) and refineries margins (Panel C), at selected horizons (impact (0) and 2 to 40 quarters), relatively to the various structural shocks: reserves (R), net negative production (Pm), net positive production (Pp), refinery margins (RM), labor supply (E), labor demand (U), aggregate demand (Y), fiscal stance (G), US fiscal deficit (Fd), US trade deficit (Td), core inflation (N), productivity (W), oil consumption (C), excess liquidity (L), risk-free rate (S), term spread (TS), real housing prices, (H), US$ exchange rate index (X), risk aversion (FV), size factor (SMB), value factor (HML), momentum factor (MOM), stocks' liquidity factor (PSL), leverage factor (LEV), Working-T index (WT), futures basis (FB), inventories (INV), real oil price (OP), nominal oil price volatility (OV), non-energy commodity price index (M), real stock prices (F), real gold price (GD), economic and financial fragility index (FRA). Figures in bold denote statistical significance at the 10% level.

Table 3: impulse response analysis, oil consumption, inventories and oil price; responses to each structural shock

Panel A: oil consumption

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	**0.04**	**-0.09**	**0.06**	-0.01	**0.07**	**-0.11**	**0.13**	0.00	-0.01	**0.11**	-0.02	**0.05**	**0.54**	0.00	0.00	0.00	0.00
2	**0.09**	-0.04	**0.07**	-0.04	**0.21**	**-0.09**	**0.13**	**-0.06**	**-0.14**	0.00	**-0.06**	**0.05**	**0.45**	**0.04**	**0.04**	0.03	**0.07**
4	**0.15**	**-0.06**	**0.08**	-0.03	**0.20**	**-0.09**	**0.12**	**-0.16**	**-0.05**	-0.02	**-0.12**	**0.14**	**0.53**	**-0.06**	**0.09**	**0.11**	**0.11**
6	**0.17**	-0.05	**0.09**	-0.06	**0.21**	**-0.10**	**0.10**	**-0.18**	0.00	0.00	**-0.12**	**0.20**	**0.58**	**-0.04**	**0.12**	**0.09**	**0.12**
8	**0.17**	0.00	0.06	-0.05	**0.14**	**-0.09**	**0.10**	**-0.16**	-0.03	0.04	**-0.13**	**0.17**	**0.59**	**-0.06**	**0.09**	**0.10**	**0.09**
12	**0.15**	0.06	0.00	-0.03	**0.08**	**-0.08**	**0.10**	**-0.13**	-0.01	**0.08**	**-0.11**	**0.14**	**0.57**	**-0.07**	**0.06**	**0.09**	0.04
20	**0.14**	0.04	-0.02	-0.01	0.04	**-0.06**	**0.10**	**-0.07**	-0.03	**0.10**	**-0.07**	**0.12**	**0.53**	**-0.06**	0.01	**0.04**	-0.01
40	**0.17**	0.07	-0.02	0.00	0.05	**-0.07**	**0.10**	**-0.09**	-0.02	**0.08**	**-0.08**	**0.15**	**0.55**	**-0.07**	0.02	**0.05**	0.01

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	-0.02	**-0.05**	**0.13**	**0.06**	**-0.05**	-0.01	**-0.06**	**-0.03**	-0.02	**0.07**	0.00	0.02	**0.03**	**0.04**	0.01	-0.01	
4	**-0.07**	**0.10**	**0.20**	**0.08**	**-0.08**	**-0.05**	**-0.13**	**-0.04**	**-0.04**	**0.06**	**-0.02**	**0.04**	-0.01	**0.03**	-0.01	0.00	
6	**-0.08**	**0.13**	**0.16**	**0.10**	**-0.08**	**-0.07**	**-0.14**	**-0.04**	**-0.02**	**0.06**	**-0.03**	**0.03**	-0.01	**0.03**	-0.01	0.01	
8	**-0.08**	**0.17**	**0.15**	**0.09**	**-0.08**	**-0.09**	**-0.15**	**-0.04**	-0.02	**0.05**	**-0.03**	0.01	-0.01	0.01	0.00	0.00	
12	**-0.10**	0.14	**0.11**	**0.12**	**-0.08**	**-0.08**	**-0.11**	**-0.04**	-0.02	0.04	**-0.03**	-0.01	-0.01	-0.01	-0.02	0.00	
20	**-0.09**	**0.07**	0.04	**0.11**	**-0.05**	**-0.05**	**-0.07**	-0.03	**-0.03**	0.02	-0.01	-0.01	-0.01	-0.02	-0.03	**-0.01**	
40	**-0.10**	**0.09**	0.04	**0.12**	**-0.06**	**-0.06**	**-0.08**	-0.03	**-0.03**	0.02	-0.01	-0.01	-0.01	**-0.02**	-0.03	**-0.01**	

Panel B: inventories

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	**0.05**	-0.01	**0.06**	-0.10	0.00	**-0.23**	**-0.24**	**-0.05**	**0.17**	-0.02	**-0.04**	**0.06**	**-0.20**	**0.09**	**0.15**	**0.15**	0.01
2	0.03	-0.03	**0.08**	-0.03	0.04	**-0.35**	**-0.30**	**-0.06**	**0.27**	**-0.11**	-0.04	**0.21**	**-0.30**	**0.17**	**0.17**	**0.13**	**0.08**
4	0.03	0.05	**0.18**	**-0.08**	-0.04	**-0.30**	**-0.23**	**0.11**	**0.14**	**-0.07**	0.07	0.01	**-0.27**	**0.22**	**0.08**	0.04	-0.01
6	0.02	**0.16**	**0.18**	-0.03	-0.04	**-0.39**	**-0.12**	**0.10**	**0.22**	**-0.07**	**0.06**	**-0.08**	**-0.22**	**0.13**	**0.05**	**0.09**	0.02
8	**0.15**	**0.13**	**0.14**	0.05	-0.03	**-0.39**	**-0.09**	**0.09**	**0.29**	**-0.11**	0.02	-0.01	**-0.21**	**0.10**	0.03	**0.09**	**0.09**
12	**0.21**	**0.27**	**0.15**	0.05	-0.01	**-0.44**	**-0.09**	0.04	**0.31**	**-0.13**	-0.02	0.08	-0.06	**0.11**	**0.09**	**0.08**	**0.16**
20	**0.20**	**0.30**	**0.10**	0.02	0.02	**-0.45**	**-0.10**	-0.01	**0.32**	**-0.14**	-0.04	0.08	-0.04	**0.09**	**0.14**	**0.11**	**0.18**
40	**0.20**	**0.31**	**0.09**	0.03	0.00	**-0.44**	**-0.09**	0.01	**0.31**	**-0.13**	-0.03	0.06	-0.06	**0.09**	**0.11**	**0.10**	**0.16**

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	**-0.18**	**-0.21**	**0.07**	**0.10**	0.00	**-0.18**	**-0.18**	**0.13**	**-0.11**	**0.50**	0.00	0.00	0.00	0.00	0.00	0.00	
2	**-0.10**	**-0.22**	**-0.08**	0.03	**0.10**	**-0.23**	**-0.10**	**0.15**	**-0.13**	**0.58**	**-0.05**	0.02	0.01	**-0.03**	**0.08**	**0.03**	
4	-0.05	**-0.37**	**-0.07**	**0.08**	**0.06**	**-0.18**	**-0.07**	**0.16**	**-0.10**	**0.51**	0.01	**-0.04**	**0.05**	-0.01	**0.05**	**-0.02**	
6	0.04	**-0.29**	0.02	0.02	**0.06**	**-0.18**	**-0.09**	**0.16**	**-0.13**	**0.45**	0.02	0.00	**0.05**	-0.01	**0.06**	-0.01	
8	**0.12**	**-0.23**	-0.02	-0.01	**0.10**	**-0.20**	**-0.11**	**0.19**	**-0.18**	**0.39**	**0.05**	**0.07**	**0.03**	**-0.03**	0.04	0.00	
12	**0.17**	**-0.13**	-0.04	-0.03	**0.10**	**-0.28**	**-0.15**	**0.22**	**-0.15**	**0.42**	0.00	**0.04**	**0.04**	**-0.03**	**0.08**	0.00	
20	**0.14**	**-0.10**	0.03	0.02	**0.06**	**-0.30**	**-0.18**	**0.20**	**-0.14**	**0.45**	-0.01	0.03	**0.04**	-0.02	**0.08**	0.00	
40	**0.14**	**-0.13**	0.01	0.02	**0.07**	**-0.29**	**-0.17**	**0.20**	**-0.15**	**0.44**	-0.01	0.03	**0.04**	-0.02	**0.08**	0.00	

Panel C: real oil price

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	**-0.92**	**1.59**	**-0.96**	**-1.44**	**-0.41**	**-1.00**	**3.13**	**0.90**	**-0.72**	**3.33**	**0.86**	**-3.29**	0.16	**1.43**	**-2.59**	**-1.93**	**-0.87**
2	**-1.03**	**3.26**	0.34	**-2.07**	**0.86**	**-2.13**	**6.57**	**-0.86**	**-1.44**	**4.04**	0.17	**-3.84**	**2.79**	**2.42**	**-3.09**	**0.51**	**0.73**
4	-0.05	0.73	**-1.85**	-0.25	**1.46**	-0.08	**4.26**	**-1.22**	-0.63	**2.79**	**-1.33**	**-1.94**	**3.12**	**1.48**	**-1.75**	0.36	**1.89**
6	0.73	-0.04	0.00	-0.55	**1.86**	-0.04	**3.12**	**-1.47**	**-0.89**	**2.02**	**-1.51**	-0.36	**2.91**	**2.16**	**-1.05**	0.14	**2.40**
8	-0.61	0.80	0.26	**-1.25**	**2.05**	-0.40	**3.16**	**-1.94**	**-1.38**	**2.38**	**-1.82**	**-1.06**	**3.54**	**2.58**	-0.51	0.27	**2.32**
12	-0.74	0.38	-0.16	**-1.39**	**2.61**	-0.61	**3.70**	**-2.23**	**-1.30**	**1.76**	**-1.74**	**-1.76**	**3.24**	**2.03**	-0.37	**0.83**	**2.61**
20	-0.91	0.38	-0.23	**-1.36**	**2.03**	**-0.63**	**3.63**	**-1.73**	**-1.12**	**2.21**	**-1.55**	**-2.00**	**3.33**	**2.21**	**-0.72**	**0.50**	**2.24**
40	-0.98	-0.01	0.03	**-1.42**	**2.27**	-0.54	**3.58**	**-1.80**	**-1.23**	**2.24**	**-1.67**	**-2.05**	**3.27**	**2.26**	**-0.67**	**0.48**	**2.32**

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	**1.23**	**-0.97**	**-1.98**	**1.03**	**1.04**	**0.32**	0.13	**0.36**	**0.30**	**-1.35**	**3.73**	0.00	0.00	0.00	0.00	0.00	
2	**2.62**	-0.25	-0.09	**0.65**	0.16	**1.48**	**-1.84**	-0.22	**2.60**	**-1.98**	**3.69**	0.21	**0.79**	**0.61**	**0.97**	-0.11	
4	**2.58**	-0.10	-0.15	**-1.18**	**1.17**	**1.60**	**-1.71**	**0.78**	**2.00**	**-2.32**	**3.63**	**1.79**	-0.13	**0.82**	**0.51**	0.13	
6	**2.31**	0.40	**-0.81**	**-1.10**	**1.36**	**0.87**	**-1.92**	**0.75**	**2.05**	**-1.56**	**3.24**	**1.75**	-0.13	**0.75**	**0.78**	**0.22**	
8	**2.30**	0.17	-0.05	**-0.59**	**0.89**	0.47	**-2.00**	**0.73**	**2.67**	**-0.66**	**2.64**	**0.83**	**0.34**	**0.98**	**1.52**	**0.17**	
12	**2.15**	0.03	**1.66**	-0.13	0.23	**0.72**	**-2.40**	**0.48**	**2.34**	**-0.71**	**2.86**	**1.06**	**0.36**	**1.27**	**1.28**	0.14	
20	**2.48**	0.08	**0.90**	-0.29	0.48	**0.63**	**-2.12**	**0.59**	**2.42**	**-0.93**	**2.92**	**0.92**	**0.37**	**1.07**	**1.33**	0.11	
40	**2.54**	0.15	**0.93**	-0.46	**0.55**	**0.65**	**-2.16**	**0.59**	**2.39**	**-0.93**	**2.95**	**1.05**	**0.32**	**1.14**	**1.34**	0.15	

The table reports impulse responses for oil consumption (Panel A), inventories (Panel B) and the real oil price (Panel C) at selected horizons (impact (0) and 2 to 40 quarters), relatively to the various structural shocks: reserves (R), net negative production (Pm), net positive production (Pp), refinery margins (RM), labor supply (E), labor demand (U), aggregate demand (Y), fiscal stance (G), US fiscal deficit (Fd), US trade deficit (Td), core inflation (N), productivity (W), oil consumption (C), excess liquidity (L), risk-free rate (S), term spread (TS), real housing prices, (H), US$ exchange rate index (X), risk aversion (FV), size factor (SMB), value factor (HML), momentum factor (MOM), stocks' liquidity factor (PSL), leverage factor (LEV), Working-T index (WT), futures basis (FB), inventories (INV), real oil price (OP), nominal oil price volatility (OV), non-energy commodity price index (M), real stock prices (F), real gold price (GD), economic and financial fragility index (FRA). Figures in bold denote statistical significance at the 10% level.

Table 4: impulse response analysis, Working's-T, futures basis, and volatility responses to each structural shock

Panel A: Working's-T

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	**0.11**	-0.04	**-0.11**	**0.17**	-0.01	**0.05**	-0.02	0.03	**-0.20**	**0.12**	**-0.08**	**-0.29**	**-0.04**	**-0.12**	-0.03	**-0.07**	**0.06**
2	0.07	**-0.11**	-0.01	0.04	**-0.23**	**0.16**	**-0.09**	**0.09**	**-0.40**	**0.16**	**-0.05**	**-0.34**	**0.15**	**-0.20**	0.02	0.00	**-0.07**
4	**-0.09**	**-0.21**	**-0.13**	**0.16**	-0.01	-0.01	**0.13**	**-0.07**	**-0.20**	**0.13**	-0.05	**-0.47**	**0.08**	**-0.35**	0.04	**0.07**	0.02
6	-0.05	**-0.19**	**-0.15**	**0.15**	0.05	**0.13**	**0.12**	-0.07	**-0.44**	**0.16**	**-0.15**	**-0.54**	**0.13**	**-0.33**	0.04	0.02	0.04
8	-0.08	**-0.21**	**-0.14**	**0.12**	0.01	**0.16**	**0.10**	-0.03	**-0.40**	**0.28**	**-0.15**	**-0.59**	**0.13**	**-0.32**	0.00	-0.02	-0.02
12	**-0.18**	**-0.34**	**-0.13**	0.11	-0.03	**0.19**	**0.10**	0.00	**-0.45**	**0.33**	**-0.15**	**-0.68**	0.06	**-0.32**	-0.05	-0.02	**-0.08**
20	**-0.27**	**-0.49**	-0.08	0.10	0.00	**0.25**	**0.11**	0.06	**-0.52**	**0.40**	**-0.15**	**-0.81**	0.00	**-0.29**	**-0.10**	-0.07	**-0.13**
40	**-0.34**	**-0.61**	-0.02	0.07	0.08	**0.26**	0.11	0.04	**-0.57**	**0.42**	**-0.19**	**-0.86**	-0.01	**-0.28**	-0.08	-0.05	-0.11

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	**0.26**	**-0.14**	**-0.15**	**-0.33**	**0.12**	0.02	**0.05**	**0.72**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	**0.14**	0.04	**-0.05**	**-0.35**	0.02	-0.01	**-0.03**	**0.68**	**0.08**	0.01	**-0.05**	**-0.14**	0.00	0.00	-0.01	-0.01	
4	**0.17**	**-0.08**	**0.20**	**-0.36**	-0.01	**0.10**	0.01	**0.68**	-0.01	0.01	**-0.03**	**-0.06**	-0.02	**0.05**	-0.03	**0.02**	
6	**0.22**	-0.06	**0.21**	**-0.44**	0.01	**0.08**	-0.03	**0.71**	0.00	-0.01	-0.02	**-0.05**	-0.01	**0.08**	-0.02	0.01	
8	**0.21**	-0.04	**0.15**	**-0.43**	0.03	**0.08**	-0.02	**0.72**	0.00	-0.05	0.01	**-0.05**	-0.02	**0.07**	-0.04	0.01	
12	**0.22**	-0.06	**0.14**	**-0.46**	0.04	**0.09**	0.01	**0.72**	-0.01	-0.05	0.02	**-0.06**	-0.02	**0.06**	-0.03	0.00	
20	**0.25**	**-0.12**	**0.13**	**-0.54**	**0.08**	**0.15**	0.05	**0.73**	-0.01	**-0.09**	**0.06**	-0.03	-0.02	**0.08**	-0.04	0.01	
40	**0.27**	-0.11	**0.19**	**-0.59**	0.07	**0.16**	0.03	**0.73**	0.00	-0.09	**0.06**	0.00	-0.03	**0.11**	-0.03	0.01	

Panel B: futures basis

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	**0.65**	**0.63**	-0.17	**-1.09**	**-0.70**	**1.01**	**-0.62**	**-0.44**	**-1.47**	-0.17	**1.30**	**-0.24**	**1.15**	**1.51**	**0.86**	**0.38**	**1.14**
2	**-1.90**	**-1.96**	-0.14	**-0.31**	0.20	**0.72**	**-3.05**	**0.40**	**0.93**	**-0.63**	**-0.46**	**0.24**	**-2.09**	**0.89**	**1.04**	-0.08	**-0.27**
4	**-0.59**	**-0.64**	**1.14**	-0.22	**-0.57**	**0.38**	**-1.32**	**0.33**	**-0.29**	**-0.71**	**-0.23**	-0.06	**-0.83**	**0.52**	**0.39**	0.18	**-0.20**
6	**-1.03**	-0.09	**0.35**	**-0.39**	0.00	**-0.36**	0.06	**0.61**	-0.05	0.02	**0.53**	**-0.93**	**-0.37**	**0.71**	**-0.18**	**-0.25**	**-0.29**
8	-0.15	**-0.77**	**0.34**	0.08	0.22	**-0.20**	**0.32**	**0.38**	-0.12	-0.52	**0.23**	**-0.68**	**-0.62**	0.02	**-0.25**	-0.02	0.09
12	**0.31**	-0.19	**0.25**	0.08	**0.24**	**-0.16**	**0.17**	0.02	**0.12**	**-0.20**	-0.05	0.15	**0.30**	0.09	0.02	-0.05	**0.36**
20	-0.05	-0.02	0.08	**-0.13**	**0.12**	0.01	**-0.07**	**-0.16**	0.02	0.01	**-0.11**	0.03	**0.10**	-0.02	**0.15**	**0.08**	0.07
40	-0.01	**-0.04**	**0.03**	-0.01	**0.03**	0.00	0.00	**-0.01**	-0.01	0.00	**-0.02**	-0.01	0.01	0.00	**0.01**	0.01	**0.02**

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	-0.02	0.07	**0.89**	**-0.14**	-0.07	**0.71**	**-0.94**	**0.24**	**4.36**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2	**-0.46**	**-0.83**	-0.23	**-0.27**	**0.57**	**-0.24**	**0.86**	**0.24**	-0.06	**1.26**	**-0.44**	**0.30**	**-0.25**	**0.12**	**0.57**	**0.24**	
4	**-0.23**	**-0.52**	**0.30**	**0.74**	**-0.30**	**-0.52**	0.06	-0.04	**0.19**	**0.90**	**-0.41**	**-0.49**	**0.31**	-0.02	**0.50**	**-0.16**	
6	**0.37**	**-1.16**	0.10	**0.34**	**-0.13**	**0.25**	**0.46**	0.01	**0.35**	**0.24**	0.01	**-0.35**	**0.36**	**0.14**	**0.33**	**-0.12**	
8	**0.42**	**-0.45**	**0.52**	0.01	-0.09	**0.18**	0.07	-0.05	**-0.26**	-0.12	**0.23**	**0.20**	**0.11**	**0.11**	-0.01	**-0.05**	
12	**0.45**	**0.21**	-0.03	**-0.26**	**0.11**	-0.07	**-0.11**	**0.10**	0.00	**-0.17**	0.05	**0.21**	0.00	0.04	0.05	0.02	
20	-0.06	**0.18**	**0.18**	0.01	**-0.06**	**-0.08**	**-0.11**	-0.02	0.03	**0.08**	**-0.06**	0.00	-0.02	**0.04**	**0.04**	**0.03**	
40	0.01	0.01	**0.03**	**-0.02**	0.00	0.00	**-0.01**	0.00	0.00	0.00	0.00	**0.01**	0.00	**0.01**	**0.01**	**0.00**	

Panel C: nominal oil price volatility

	R	Pm	Pp	RM	E	U	Y	G	Fd	Td	N	W	C	L	SR	TS	H
0	**-0.13**	**0.74**	**0.32**	**0.16**	**0.37**	**0.30**	0.02	**-0.12**	**0.27**	**-0.12**	**0.12**	**0.09**	**-0.39**	0.05	0.03	**-0.26**	0.01
2	-0.03	0.14	**0.82**	**0.65**	0.00	**0.52**	**-0.35**	-0.07	**0.59**	**-0.18**	0.00	**0.60**	**-0.42**	**-0.21**	0.06	**-0.10**	0.02
4	**-0.39**	**-0.40**	**1.18**	**0.48**	0.15	**0.33**	**-0.12**	0.02	**0.23**	0.05	0.06	**0.32**	**-0.29**	0.08	-0.02	**-0.42**	-0.02
6	**-0.65**	**-0.52**	**1.05**	**0.51**	**0.42**	**0.27**	**0.26**	0.00	**-0.18**	-0.07	0.07	**-0.16**	**-0.29**	0.08	-0.06	**-0.38**	0.09
8	**-0.55**	**-0.65**	**1.00**	**0.58**	**0.46**	**0.37**	0.12	-0.06	0.04	-0.23	-0.01	-0.08	**-0.37**	-0.04	0.02	**-0.24**	**0.16**
12	**-0.52**	**-0.79**	**1.24**	**0.55**	**0.38**	**0.44**	-0.06	-0.04	0.13	-0.09	-0.12	0.07	**-0.35**	0.04	0.04	**-0.28**	0.14
20	**-0.64**	**-0.85**	**1.18**	**0.59**	**0.38**	**0.46**	0.03	0.05	0.03	-0.03	-0.11	-0.18	**-0.38**	0.02	-0.05	**-0.31**	0.10
40	**-0.75**	**-1.02**	**1.26**	**0.52**	**0.48**	**0.46**	0.07	0.03	-0.03	0.00	-0.15	**-0.29**	**-0.39**	0.04	-0.04	**-0.31**	0.13

	X	FV	SMB	HML	MOM	PSL	LEV	WT	FB	INV	OP	OV	M	F	GD	FRA	
0	**0.49**	-0.02	**-0.10**	**-0.28**	**0.51**	**0.09**	**0.16**	**-0.43**	**-0.15**	**-0.44**	**0.22**	**0.98**	0.00	0.00	0.00	0.00	
2	**0.46**	**0.32**	**-0.54**	**-1.05**	**0.94**	**0.25**	**0.31**	**-0.31**	**-0.21**	**-0.61**	**0.18**	**1.28**	**-0.27**	**-0.12**	**-0.07**	**0.14**	
4	**0.74**	0.11	**-0.74**	**-1.00**	**0.96**	0.11	**0.44**	**-0.25**	**-0.10**	**-0.46**	**0.10**	**1.00**	**-0.08**	**-0.09**	**0.14**	**0.09**	
6	**0.96**	-0.22	**-0.25**	**-1.06**	**0.83**	**0.26**	**0.41**	**-0.26**	-0.05	**-0.42**	**0.12**	**0.95**	0.06	**0.06**	**0.23**	**0.05**	
8	**0.86**	-0.18	-0.04	**-1.05**	**0.79**	**0.34**	**0.33**	**-0.27**	**-0.13**	**-0.50**	**0.18**	**1.14**	-0.03	**0.09**	**0.13**	**0.07**	
12	**0.89**	0.04	**-0.31**	**-1.11**	**0.91**	**0.20**	**0.33**	**-0.23**	**-0.10**	**-0.50**	**0.15**	**1.17**	**-0.07**	0.03	**0.17**	**0.09**	
20	**1.01**	-0.04	**-0.25**	**-1.18**	**0.92**	**0.24**	**0.36**	**-0.20**	**-0.12**	**-0.56**	**0.19**	**1.17**	-0.05	0.05	**0.19**	**0.08**	
40	**1.06**	-0.03	-0.14	**-1.24**	**0.91**	**0.27**	**0.34**	**-0.20**	**-0.11**	**-0.56**	**0.21**	**1.19**	-0.04	0.09	**0.21**	**0.09**	

The table reports impulse responses for Working-T index (Panel A), futures basis (Panel B) and nominal oil price volatility (Panel C) at selected horizons (impact (0) and 2 to 40 quarters), relatively to the various structural shocks: reserves (R), net negative production (Pm), net positive production (Pp), refinery margins (RM), labor supply (E), labor demand (U), aggregate demand (Y), fiscal stance (G), US fiscal deficit (Fd), US trade deficit (Td), core inflation (N), productivity (W), oil consumption (C), excess liquidity (L), risk-free rate (S), term spread (TS), real housing prices, (H), US$ exchange rate index (X), risk aversion (FV), size factor (SMB), value factor (HML), momentum factor (MOM), stocks' liquidity factor (PSL), leverage factor (LEV), Working-T index (WT), futures basis (FB), inventories (INV), real oil price (OP), nominal oil price volatility (OV), non-energy commodity price index (M), real stock prices (F), real gold price (GD), economic and financial fragility index (FRA). Figures in bold denote statistical significance at the 10% level.

Table 5: real oil price and nominal oil price volatility (net of base prediction), historical decomposition (2004-2010), contribution of various categories of shocks.

	Panel A: real oil price									Panel B: nominal oil price volatility									
	SUP	**C**	**INV**	**MAC**	**X**	**FIN**	**SPC**	**OWN**	**WTI**	**SUP**	**C**	**INV**	**MAC**	**X**	**FIN**	**SPC**	**OP**	**OWN**	**WTIv**
04(1)	-2.6	2.1	-1.6	5.5	-0.8	15.6	-5.2	-2.0	**11.1**	1.2	-0.2	-0.5	-1.7	0.4	-0.9	-0.4	-0.1	-0.4	**-2.5**
04(2)	-2.0	2.7	-0.6	7.1	-2.0	-6.0	4.6	2.9	**6.7**	1.5	-0.1	0.5	-1.8	-0.6	-1.9	0.3	0.1	0.7	**-1.1**
04(3)	1.6	-0.1	0.8	0.1	-2.9	7.8	2.7	2.9	**12.9**	2.2	-0.9	0.5	0.3	-0.3	-0.5	0.2	0.3	0.2	**2.0**
04(4)	5.0	6.1	-2.6	-2.6	1.1	6.0	0.9	-5.3	**8.8**	0.4	-0.2	-0.6	0.2	0.8	1.9	-0.2	-0.2	0.3	**2.4**
05(1)	2.4	-0.6	-1.3	-1.7	1.6	-1.8	-0.4	3.7	**2.0**	-0.5	-0.1	0.0	1.4	-0.5	0.4	-0.8	0.0	1.7	**1.6**
05(2)	-2.2	-2.7	1.3	0.5	-1.5	3.6	2.6	3.2	**4.9**	0.8	0.4	-0.6	1.1	-0.8	-1.3	-0.8	0.2	0.1	**-0.9**
05(3)	-0.4	-1.1	-0.1	20.0	-2.2	-6.1	0.6	5.3	**15.8**	1.2	1.0	0.1	-2.0	-0.1	1.2	-0.1	0.4	-1.3	**0.5**
05(4)	-0.9	-5.5	-0.7	11.1	-1.3	-9.1	2.1	-1.5	**-5.8**	0.7	0.1	-0.4	-0.7	-0.1	0.0	-1.0	-0.3	-1.1	**-2.8**
06(1)	-0.9	-0.4	1.4	3.1	-1.0	6.9	-6.3	1.6	**4.5**	0.9	-0.2	0.5	-0.7	0.4	-1.2	1.2	-0.2	-1.6	**-0.8**
06(2)	0.5	2.9	2.9	-14.1	1.0	22.1	1.3	-7.9	**8.7**	0.4	0.3	0.9	0.2	0.1	-1.1	0.8	-0.4	-1.2	**0.0**
06(3)	2.0	-4.4	0.9	-18.8	1.0	11.5	5.8	1.1	**-0.9**	0.5	-0.5	0.0	1.5	-0.3	-3.9	0.0	0.1	0.4	**-2.1**
06(4)	4.4	0.2	-1.6	-20.2	-1.0	3.6	-4.3	3.3	**-15.5**	0.3	0.5	-0.3	3.1	-0.4	-1.1	0.3	0.2	-0.8	**1.7**
07(1)	1.1	-1.9	3.8	-2.4	2.0	-9.5	1.2	1.3	**-4.6**	0.2	-0.1	0.5	0.2	1.1	0.1	-0.3	0.2	0.1	**2.0**
07(2)	0.0	-2.2	2.4	6.3	4.3	-7.3	3.2	2.4	**9.1**	0.3	-0.6	0.3	-2.3	0.3	-0.2	0.0	0.2	1.6	**-0.3**
07(3)	-2.0	5.7	-0.7	6.9	0.9	4.1	-3.9	3.5	**14.6**	0.8	0.3	0.2	-2.0	-0.5	0.3	0.1	0.0	-0.1	**-0.9**
07(4)	-0.3	-1.0	-2.6	13.5	2.0	12.1	-6.1	-0.4	**17.3**	0.9	-0.5	-0.8	-1.3	1.8	2.1	-0.9	0.0	-0.2	**1.0**
08(1)	2.2	2.0	-3.0	14.0	1.8	0.2	-3.2	-7.6	**6.3**	0.5	0.5	-0.5	-1.3	0.0	1.3	0.6	-0.5	-2.1	**-1.6**
08(2)	1.4	-0.6	-0.9	16.7	1.4	-4.1	4.4	3.0	**21.1**	0.1	-0.1	0.2	-1.1	1.1	2.6	-0.2	0.0	-1.8	**0.7**
08(3)	-3.6	-0.5	0.9	1.8	1.3	-1.1	1.9	-7.2	**-6.5**	0.5	0.6	0.3	-1.9	0.3	1.7	-0.5	-0.3	-0.5	**0.1**
08(4)	-2.1	-3.5	-2.0	-39.3	-2.6	-11.1	-2.5	-4.5	**-67.4**	2.5	-0.1	0.0	4.6	-0.9	2.7	0.0	0.0	1.4	**10.1**
09(1)	7.2	0.7	-0.9	-26.3	-2.7	-6.9	-0.3	-1.5	**-30.6**	-0.2	-0.1	0.2	4.1	1.0	0.6	0.0	0.1	0.6	**6.2**
09(2)	2.8	2.9	1.4	6.1	0.0	12.4	4.3	1.3	**31.3**	-1.3	-0.4	0.1	2.6	-0.6	-2.4	0.1	0.2	0.7	**-1.0**
09(3)	0.0	0.0	2.5	9.9	0.4	-1.6	1.2	0.1	**12.6**	-1.6	-0.1	0.5	0.4	0.0	-1.7	-0.1	0.3	0.1	**-2.3**
09(4)	-2.5	0.3	0.1	4.6	0.7	3.5	0.1	3.6	**10.5**	-0.2	0.1	-0.3	-3.0	0.0	-1.4	0.1	0.0	0.5	**-4.2**
10(1)	-0.6	-1.1	-1.1	3.5	-1.2	-1.8	2.3	2.8	**2.7**	-0.2	0.2	-0.3	-3.9	-0.9	-0.3	0.1	0.0	0.8	**-4.4**
10(2)	-3.2	-0.5	2.3	6.2	-2.3	-7.3	0.9	2.1	**-1.9**	1.0	-0.7	0.7	-0.4	0.1	-0.9	-0.3	0.0	-1.0	**-1.5**
10(3)	-4.3	6.0	1.8	-6.5	1.3	-2.7	2.7	-0.9	**-2.6**	1.1	-0.6	0.2	0.7	0.4	0.0	-1.2	-0.2	-1.3	**-0.9**
TOT	**3.2**	**5.5**	**3.1**	**5.1**	**-0.8**	**32.9**	**10.5**	**5.5**	**65.0**	**13.8**	**-1.5**	**1.3**	**-3.7**	**1.8**	**-3.8**	**-2.9**	**0.3**	**-4.3**	**1.1**

The table reports the historical decomposition (net of base prediction) for the real oil price growth rate and nominal oil price volatility in changes over the period 2005-1010, relatively to subsets of structural shocks (net of the contribution of the own shock) : oil supply shocks (SUP, reserves, net production changes, refinery margins), oil consumption shocks (C), inventories shocks (INV), macroeconomic shocks (MAC: labor supply and demand, aggregate demand, fiscal stance, US fiscal and trade deficit, core inflation, productivity), US$ exchange rate index shocks (X), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, real housing prices, risk aversion, size, value, momentum, liquidity and leverage factors, real commodity prices, real stock prices, economic and financial fragility index, nominal oil price volatility), financial speculation (SPC: Working-T index, futures basis), the real oil price (OP), and the own shock (OWN). WTI denotes the actual real oil price growth rate and WTIv the actual nominal oil price volatility in changes (both net of base prediction); TOT denotes the cumulative contribution over the 2004:1 through 2010:3 period.

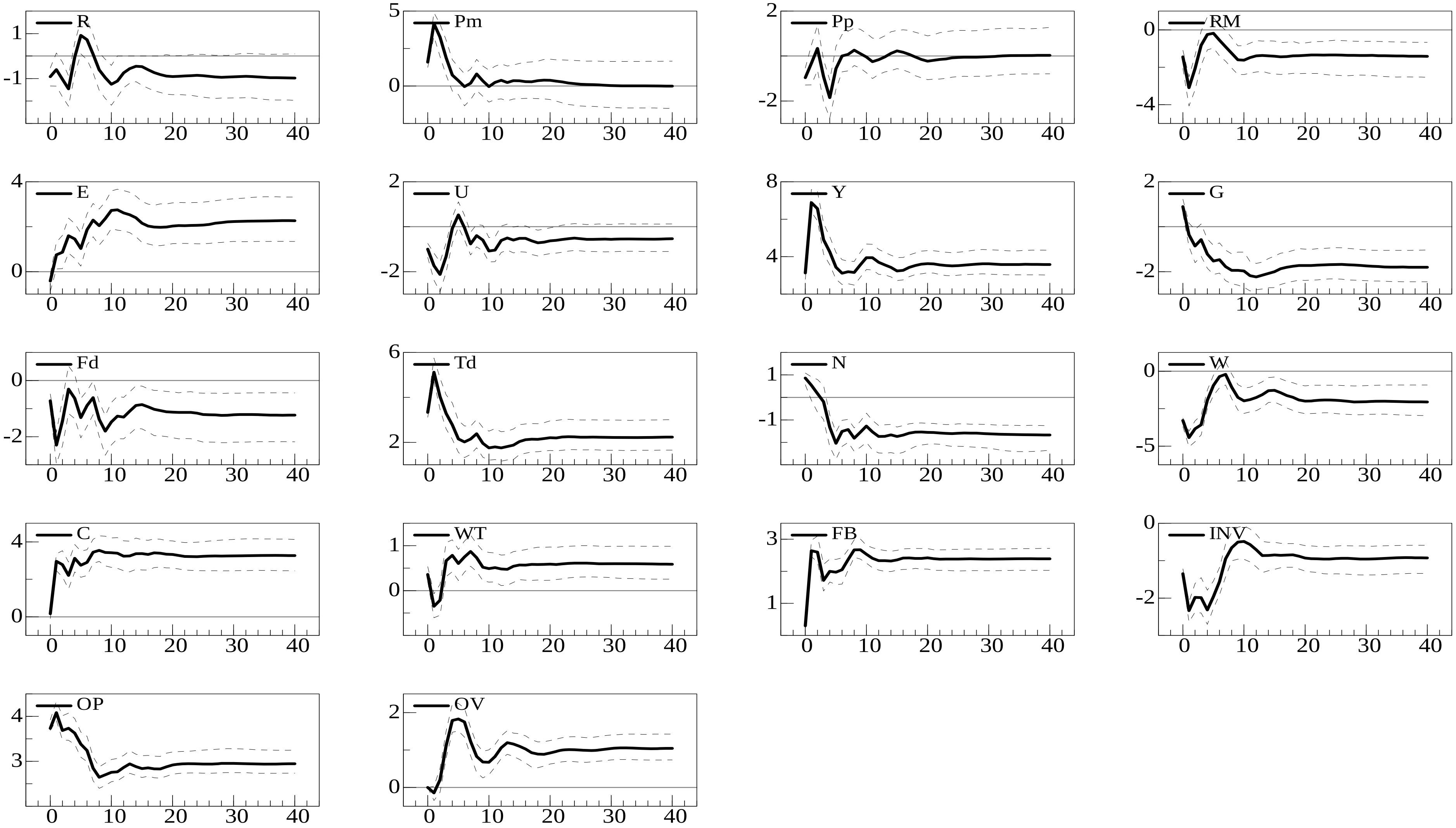

Figure 1: Impulse responses for the real oil price to various structural shocks (median and 95% confidence interval): reserves (R), net negative production (Pm), net positive production (Pp), refinery margins (RM), labor supply (E), labor demand (U), aggregate demand (Y), fiscal stance (G), US fiscal deficit (Fd), US trade deficit (Td), core inflation (N), productivity (W), oil consumption (C), Working-T index (WT), futures basis (FB), inventories (INV), real oil price (OP), nominal oil price volatility (OV).

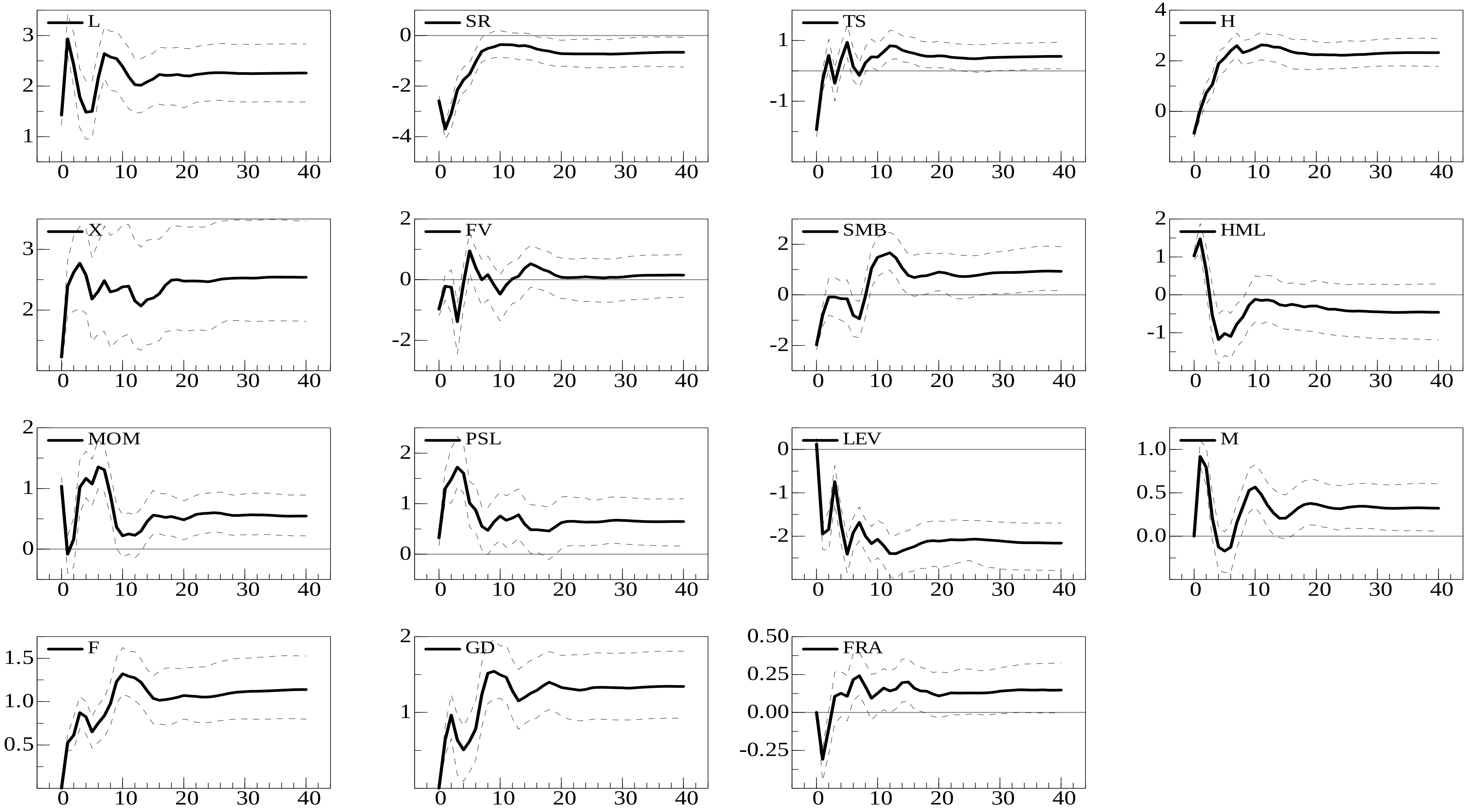

Figure 2: Impulse responses for the real oil price to various structural shocks (median and 95% confidence interval): excess liquidity (L), risk-free rate (S), term spread (TS), housing price, (H), US$ exchange rate index (X), risk aversion (FV), size factor (SMB), value factor (HML), momentum factor (MOM), stocks' liquidity factor (PSL), leverage factor (LEV), non-energy commodity price index (M), stock prices (F), gold price (GD), fragility (FRA).

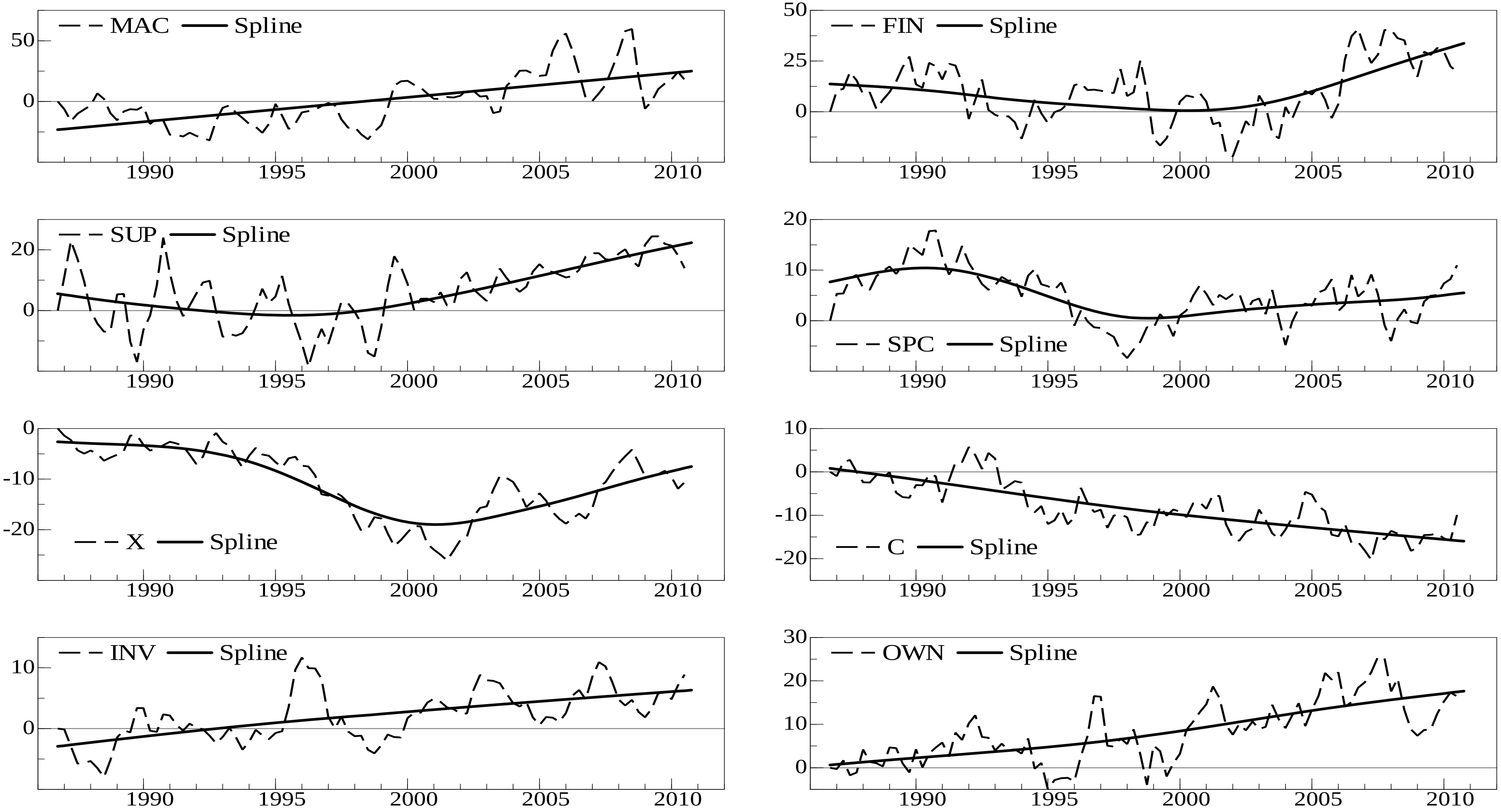

Figure 3: Cumulative contribution of various categories of shocks to the real oil price (dashed line) and spline smoother (solid line); 1986(4)-20010(3); supply side shocks (SUP: reserves, net negative and positive production, refinery margins), oil consumption own shock (C), inventories (I), macroeconomic shocks (MAC: labor supply, labor demand, aggregate demand, fiscal stance, US fiscal deficit, US trade deficit, core inflation, productivity), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, housing prices, risk aversion, size, value, momentum, stocks' liquidity and leverage factors, non-energy commodity prices, stock prices, gold prices, fragility factor) , US$ exchange rate shocks (X), non-fundamental financial shocks (SPC: Working-T index, futures basis), real oil price own shock (OWN).

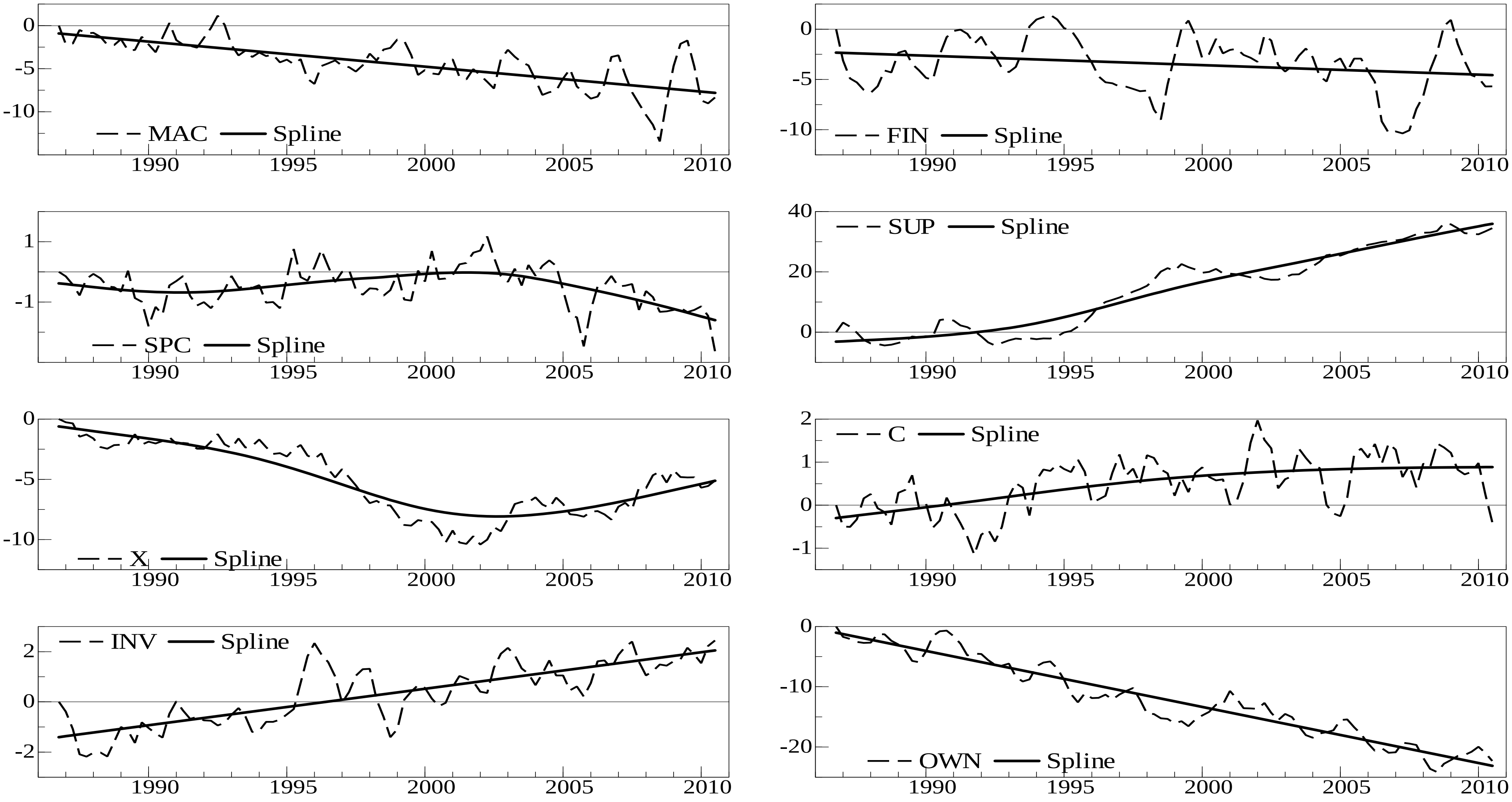

Figure 4: Cumulative contribution of various categories of shocks to the nominal oil price volatility (dashed line) and spline smoother (solid line); 1986(4)-20010(3); supply side shocks (SUP: reserves, net negative and positive production, refinery margins), oil consumption own shock (C), inventories (I), macroeconomic shocks (MAC: labor supply, labor demand, aggregate demand, fiscal stance, US fiscal deficit, US trade deficit, core inflation, productivity), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, housing prices, risk aversion, size, value, momentum, stocks' liquidity and leverage factors, non-energy commodity prices, stock prices, gold prices, fragility factor) , US$ exchange rate shocks (X), non-fundamental financial shocks (SPC: Working-T index, futures basis), nominal oil price volatility own shock (OWN) .

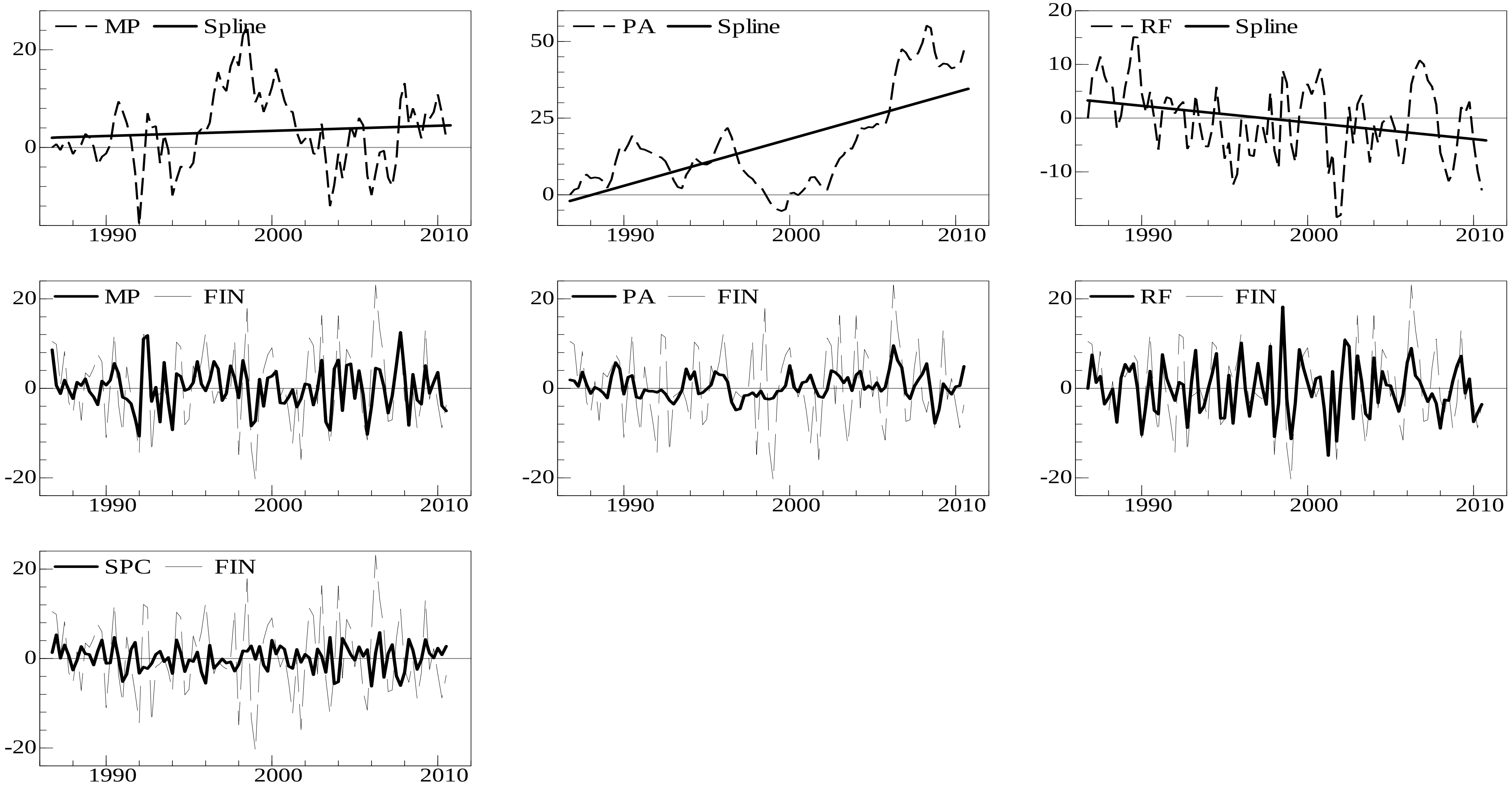

Figure 5: Cumulative contribution of various categories of fundamental financial shocks to the real oil price (dashed line) and spline smoother (solid line) (top plots), contribution of various categories of fundamental financial shocks to the fundamental financial component of real oil price growth (center plots) and relative dimension of non-fundamental and fundamental financial shocks (bottom plot); 1986(4)-20010(3). Contributions from liquidity and interest rate shocks (MP: excess liquidity, risk-free rate, term spread), portfolio allocation shocks (PA: housing prices, non-energy commodity prices, stock prices, gold price) and risk factors shocks (RF: risk aversion, size factor, value factor, momentum factor, stocks' liquidity factor, leverage factor, fragility factor). SPC is the non-fundamental financial component of the real oil price growth rate (SPC: Working-T index + futures basis); FIN is the fundamental financial component of the real oil price growth rate (FIN: MP + PA + RF).

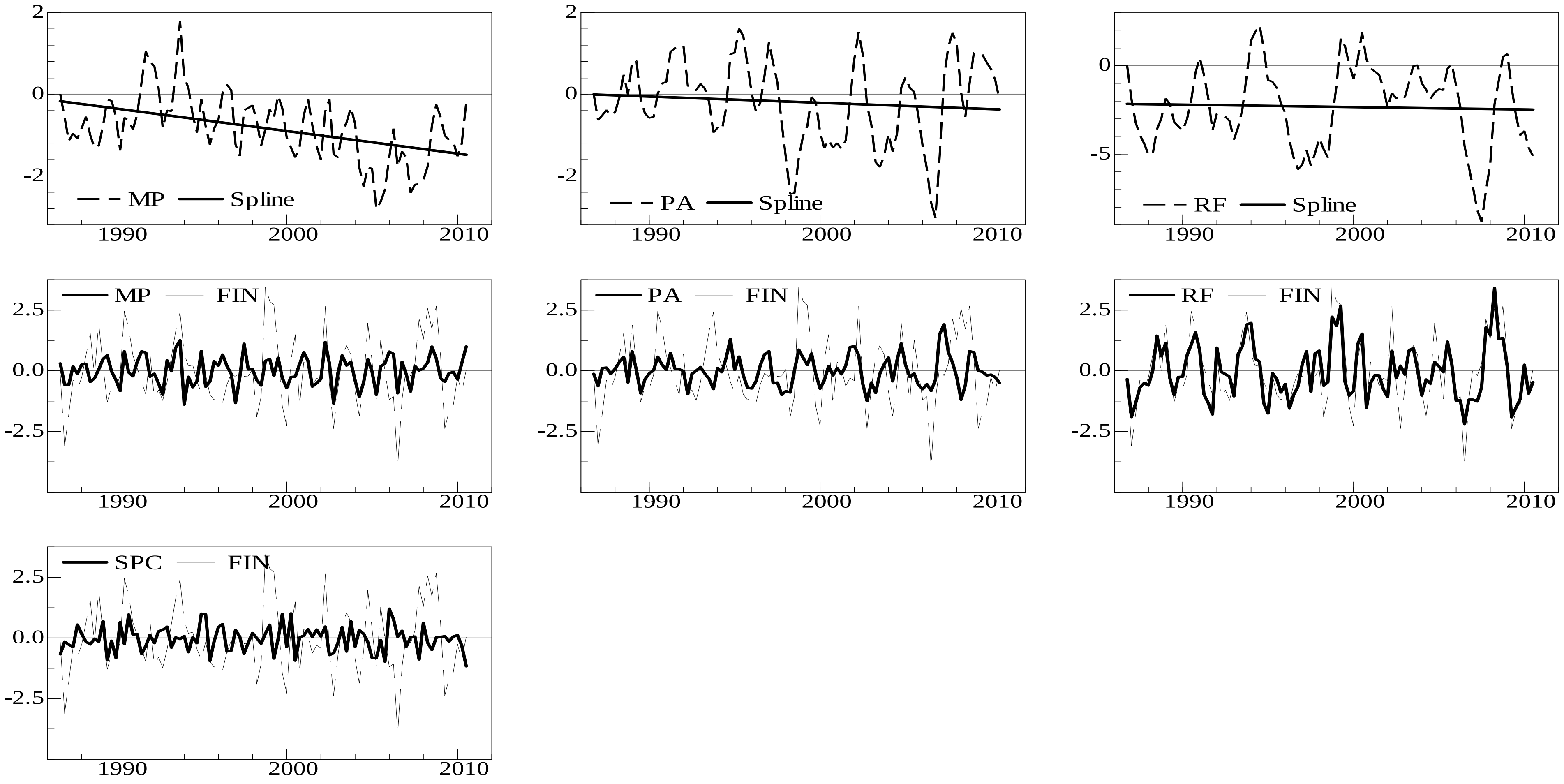

Figure 6: Cumulative contribution of various categories of fundamental financial shocks to nominal oil price volatility (dashed line) and spline smoother (solid line) (top plots), contribution of various categories of fundamental financial shocks to the fundamental financial component of nominal oil price volatility changes (center plots) and relative dimension of non-fundamental and fundamental financial shocks (bottom plot); 1986(4)-20010(3). Contributions from liquidity and interest rate shocks (MP: excess liquidity, risk-free rate, term spread), portfolio allocation shocks (PA: housing prices, non-energy commodity prices, stock prices, gold price) and risk factors shocks (RF: risk aversion, size factor, value factor, momentum factor, stocks' liquidity factor, leverage factor, fragility factor). SPC is the non-fundamental financial component of nominal oil price volatility changes (SPC: Working-T index + futures basis); FIN is the fundamental financial component of nominal oil price volatility (FIN: MP + PA + RF).

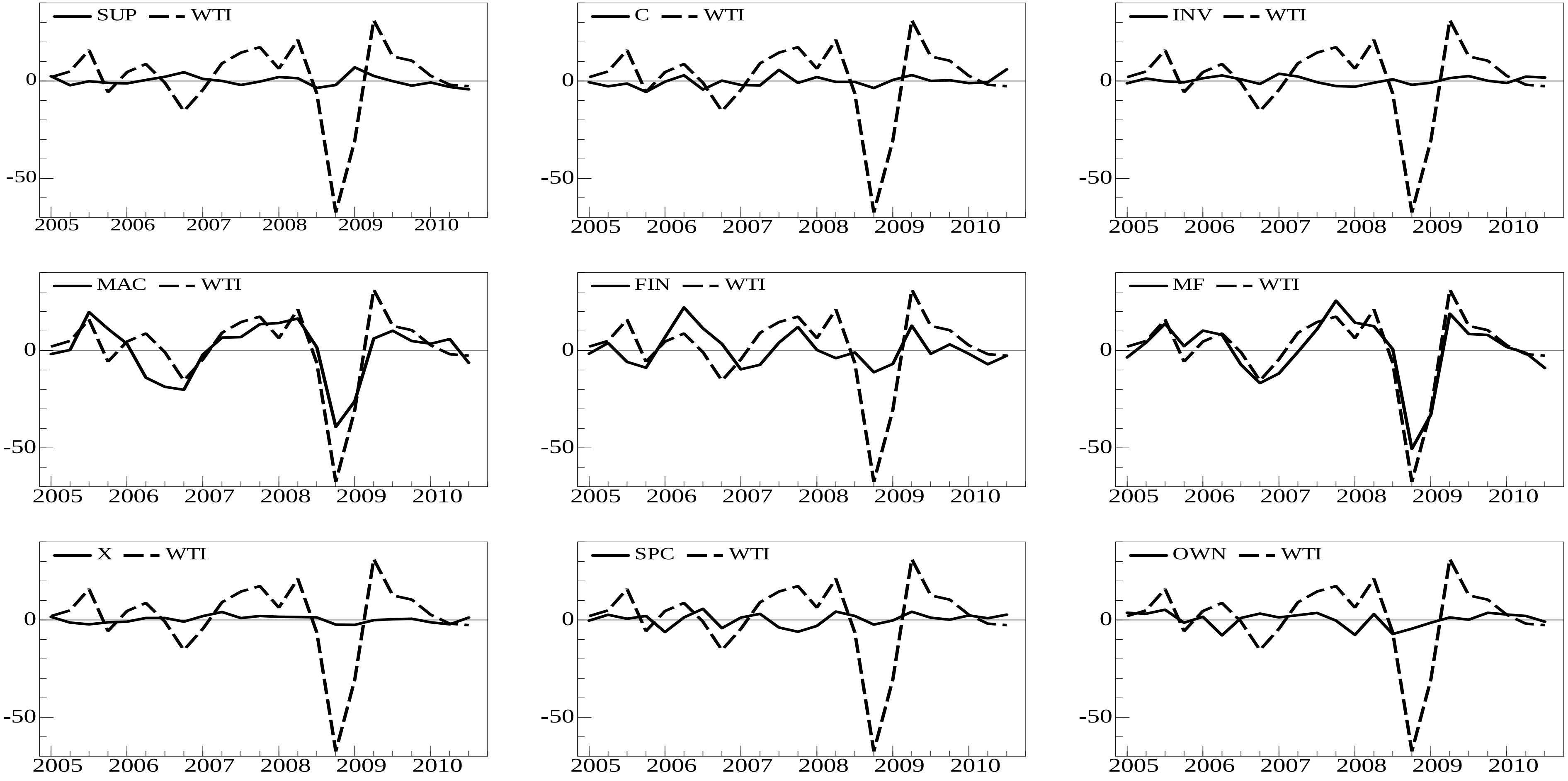

Figure 7: Historical decomposition for the real WTI oil price growth rate (dashed line); 2005(1)-20010(3): the third oil price shock. Contributions from the oil market supply side shocks (SUP: reserves, net negative and positive production, refinery margins), oil consumption own shock (C), inventories (I), macroeconomic shocks (MAC: labor supply, labor demand, aggregate demand, fiscal stance, US fiscal and trade deficits, core inflation and productivity), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, housing prices, risk aversion, size, value, momentum, stocks' liquidity, and leverage factors, nominal oil price volatility, non-energy commodity prices, stock prices, gold prices, fragility factor), macro-financial shocks (MF: MAC+FIN), US$ exchange rate shocks (X), non-fundamental financial shocks (SPC: Working-T index, futures basis), real oil price own shock (OWN).

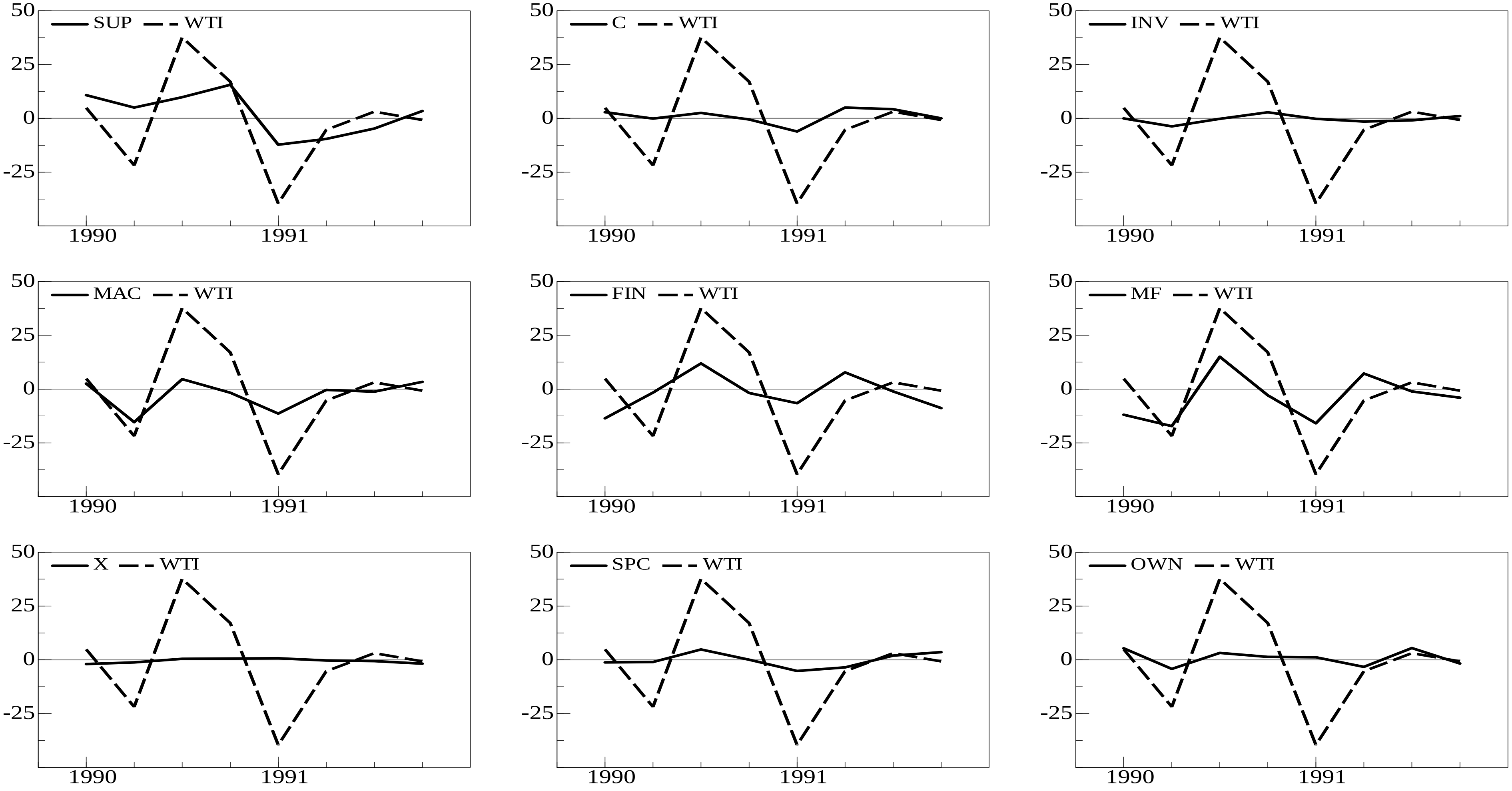

Figure 8: Historical decomposition for the real WTI oil price growth rate (dashed line); 1990-1991: First Persian Gulf War. Contributions from the oil market supply side shocks (SUP: reserves, net negative and positive production, refinery margins), oil consumption own shock (C), inventories (I), macroeconomic shocks (MAC: labor supply, labor demand, aggregate demand, fiscal stance, US fiscal and trade deficits, core inflation and productivity), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, housing prices, risk aversion, size, value, momentum, stocks' liquidity, and leverage factors, nominal oil price volatility, non-energy commodity prices, stock prices, gold prices, fragility factor), macro-financial shocks (MF: MAC+FIN), US$ exchange rate shocks (X), non-fundamental financial shocks (SPC: Working-T index, futures basis), real oil price own shock (OWN).

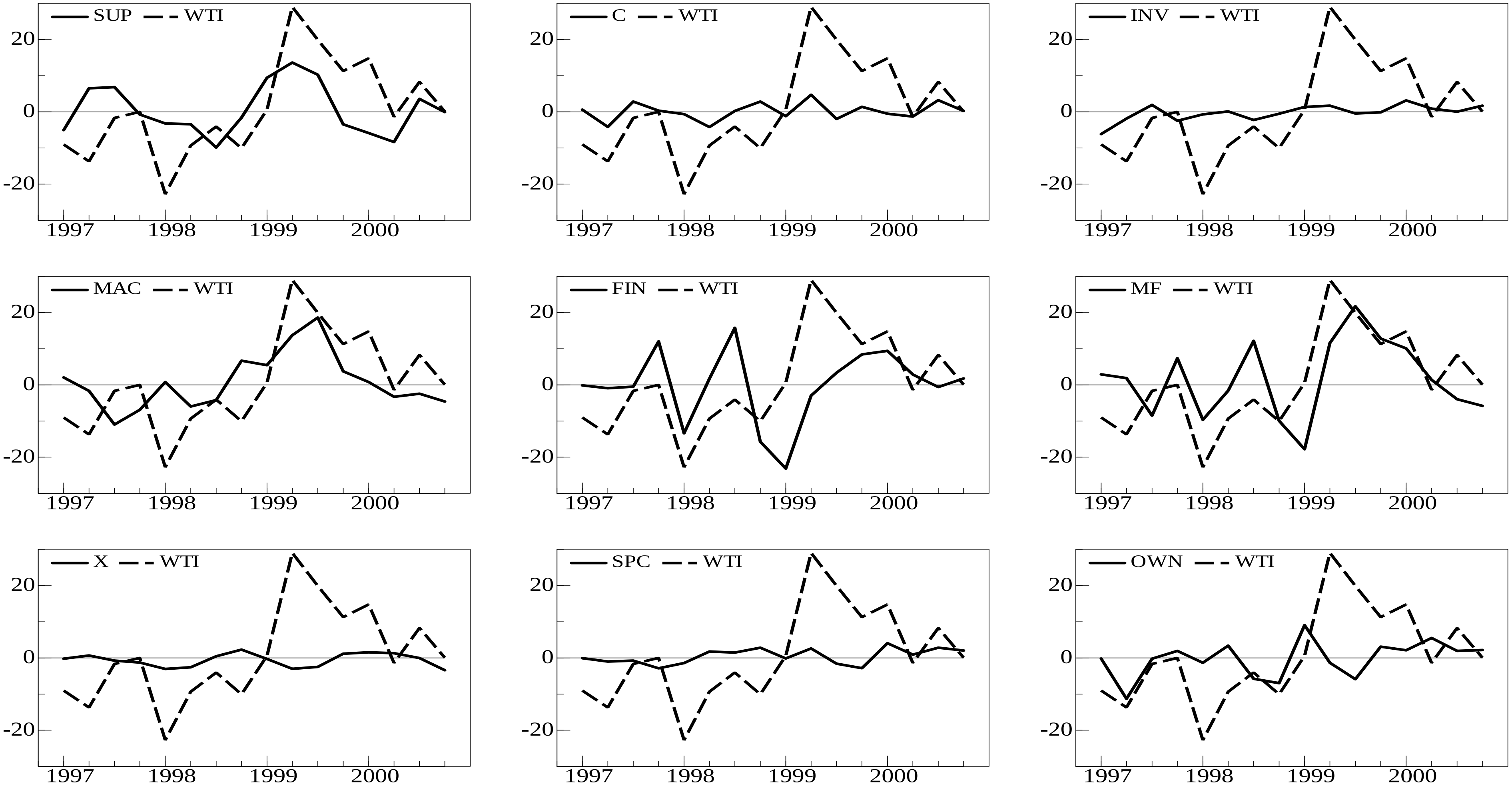

Figure 9: Historical decomposition for the real WTI oil price growth rate (dashed line); 1997-2000: East Asia crisis and recovery. Contributions from the oil market supply side shocks (SUP: reserves, net negative and positive production, refinery margins), oil consumption own shock (C), inventories (I), macroeconomic shocks (MAC: labor supply, labor demand, aggregate demand, fiscal stance, US fiscal and trade deficits, core inflation and productivity), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, housing prices, risk aversion, size, value, momentum, stocks' liquidity, and leverage factors, nominal oil price volatility, non-energy commodity prices, stock prices, gold prices, fragility factor), macro-financial shocks (MF: MAC+FIN), US$ exchange rate shocks (X), non-fundamental financial shocks (SPC: Working-T index, futures basis), real oil price own shock (OWN).

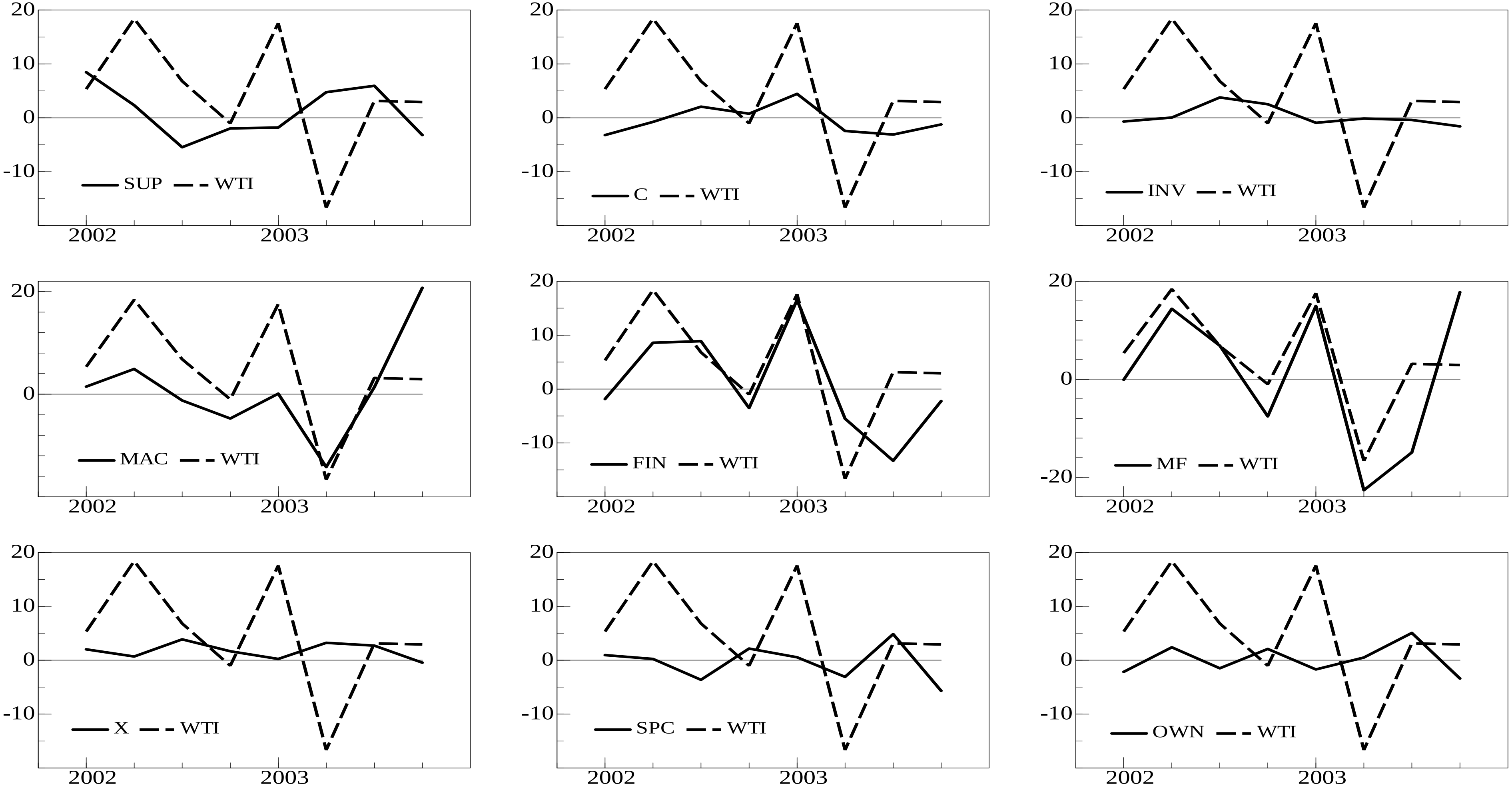

Figure 10: Historical decomposition for the real WTI oil price growth rate (dashed line); 2002-2003: Venezuelan strike and second Persian Gulf War. Contributions from the oil market supply side shocks (SUP: reserves, net negative and positive production, refinery margins), oil consumption own shock (C), inventories (I), macroeconomic shocks (MAC: labor supply, labor demand, aggregate demand, fiscal stance, US fiscal and trade deficits, core inflation and productivity), fundamental financial shocks (FIN: excess liquidity, risk-free rate, term spread, housing prices, risk aversion, size, value, momentum, stocks’ liquidity, and leverage factors, nominal oil price volatility, non-energy commodity prices, stock prices, gold prices, fragility factor), macro-financial shocks (MF: MAC+FIN), US$ exchange rate shocks (X), non-fundamental financial shocks (SPC: Working-T index, futures basis), real oil price own shock (OWN).

9 Appendix: Econometric methodology

The econometric model is described by two blocks of equations. The former refers to the *observed* $(\mathbf{F}_{2,t})$ and *unobserved* $(\mathbf{F}_{1,t})$ global macro-financial factors and oil market demand and supply side variables $(\mathbf{O}_t)$, collected in the $r\times 1$ vector $\mathbf{F}_t = \left[\mathbf{F}_{1,t}' \ \mathbf{F}_{2,t}' \ \mathbf{O}_t'\right]'$, while the latter to q macro-financial variables for m countries ($n = m \times q$ equations in total). The joint dynamics of the "global" macro-finance-oil market interface (the global economy thereafter) and the "local" macro-finance interface are then modelled by means of the following reduced form dynamic factor model

$$\begin{aligned}
(\mathbf{I}-\mathbf{P}(L))\mathbf{F}_t-\boldsymbol{\kappa}_t &= \boldsymbol{\eta}_t && (7)\\
\boldsymbol{\eta}_t &\sim i.i.d.(\mathbf{0},\boldsymbol{\Sigma}_\eta) && (8)\\
(\mathbf{I}-\mathbf{C}(L))\left((\mathbf{Z}_t-\boldsymbol{\mu}_t)-\boldsymbol{\Lambda}\left(\mathbf{F}_t-\boldsymbol{\kappa}_t\right)\right) &= \mathbf{v}_t && (9)\\
\mathbf{v}_t &\sim i.i.d.(\mathbf{0},\boldsymbol{\Sigma}_v). && (10)
\end{aligned}$$

The model is cast in a weakly stationary representation, as $(\mathbf{F}_t-\boldsymbol{\kappa}_t), (\mathbf{Z}_t-\boldsymbol{\mu}_t) \sim I(0)$, where $\boldsymbol{\mu}_t$ and $\boldsymbol{\kappa}_t$ are $n \times 1$ and $r \times 1$ vectors of deterministic components, respectively, with $r \leq n$, including an intercept term, and, possibly, linear or non linear trends components.

Global dynamics are described by the stationary finite order polynomial matrix in the lag operator $\mathbf{P}(L)$, $\mathbf{P}(L) \equiv \mathbf{P}_1 L + \mathbf{P}_2 L^2 + ... + \mathbf{P}_p L^p$, where $\mathbf{P}_j$, $j = 1,..,p$, is a square matrix of coefficients of order r, and $\boldsymbol{\eta}_t$ is a $r \times 1$ vector of i.i.d. reduced form shocks driving the $\mathbf{F}_t$ factors. The contemporaneous effects of the global factors on each country variables in $\mathbf{Z}_t$ are measured by the loading coefficients collected in the $n \times r$ matrix $\boldsymbol{\Lambda} = \left[\boldsymbol{\Lambda}_{F_1}' \ \boldsymbol{\Lambda}_{F_2}' \ \boldsymbol{\Lambda}_O'\right]'$. Finally, $\mathbf{C}(L)$ is a finite order stationary block (own country) diagonal polynomial matrix in the lag operator, $\mathbf{C}(L) \equiv \mathbf{C}_1 L + \mathbf{C}_2 L^2 + ... + \mathbf{C}_c L^c$, where $\mathbf{C}_j$, $j = 1,..,c$, is a square matrix of coefficients of order n, partitioned as

$$\underset{n\times n}{\mathbf{C}_j} = \begin{bmatrix} \underset{q\times q}{\mathbf{C}_{j,11}} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \underset{q\times q}{\mathbf{C}_{j,22}} & \cdots & \mathbf{0} \\ \vdots & \cdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \underset{q\times q}{\mathbf{C}_{j,mm}} \end{bmatrix}, \tag{11}$$

and $\mathbf{v}_t$ is the $n \times 1$ vector of i.i.d. reduced-form idiosyncratic (i.e. country-specific) disturbances. It is assumed that $E\left[\eta_{jt} v_{is}\right] = 0$ for all i, j, t, s.

The specification of the model in (7)-(9) embeds a set of important assumptions on the structure of global and local linkages: (i) global shocks

($\boldsymbol{\eta}_t$) affect both the global and local economy through the polynomial matrix $\mathbf{P}(L)$ and the factor loading matrix $\boldsymbol{\Lambda}$; (ii) idiosyncratic disturbances ($\mathbf{v}_t$) do not affect the global economy, while impact on the local economy only through own-country linkages ($\mathbf{C}(L)$ is block (own country) diagonal).

By substituting (7) into (9), the reduced form vector autoregressive (VAR) representation of the dynamic factor model can be written as

$$(\mathbf{I} - \mathbf{A}(L))\left(\mathbf{Y}_t - \boldsymbol{\gamma}_t\right) = \boldsymbol{\varepsilon}_t \tag{12}$$

where $\mathbf{Y}_t = [\mathbf{F}_t' \ \mathbf{Z}_t']'$, $\boldsymbol{\gamma}_t = [\boldsymbol{\kappa}_t' \ \boldsymbol{\mu}_t']'$,

$$\mathbf{A}(L) = \begin{pmatrix} \mathbf{P}(L) & \mathbf{0} \\ [\boldsymbol{\Lambda}\mathbf{P}(L) - \mathbf{C}(L)\boldsymbol{\Lambda}] & \mathbf{C}(L) \end{pmatrix},$$

$$\boldsymbol{\varepsilon}_t \equiv \begin{bmatrix} \boldsymbol{\varepsilon}_{1,t} \\ \boldsymbol{\varepsilon}_{2,t} \end{bmatrix} = \begin{bmatrix} \mathbf{I} \\ \boldsymbol{\Lambda} \end{bmatrix} [\boldsymbol{\eta}_t] + \begin{bmatrix} \mathbf{0} \\ \mathbf{v}_t \end{bmatrix},$$

with variance-covariance matrix

$$E\left[\boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}_t'\right] = \boldsymbol{\Sigma}_\varepsilon = \begin{pmatrix} \boldsymbol{\Sigma}_\eta & \boldsymbol{\Sigma}_\eta \boldsymbol{\Lambda}' \\ \boldsymbol{\Lambda}\,\boldsymbol{\Sigma}_\eta & \boldsymbol{\Lambda}\,\boldsymbol{\Sigma}_\eta \boldsymbol{\Lambda}' + \boldsymbol{\Sigma}_v \end{pmatrix},$$

where $E\left[\boldsymbol{\eta}_t \boldsymbol{\eta}_t'\right] = \boldsymbol{\Sigma}_\eta$ and $E\left[\mathbf{v}_t \mathbf{v}_t'\right] = \boldsymbol{\Sigma}_v$.

9.1 Estimation

Consistent and asymptotically Normal estimation of the model can be achieved following the multi-step iterative procedure described in Morana (2011a), which, for the current application, consists of the following steps.

- **Step 1: initialization.**

An initial estimate of the r_1 unobserved common factors in $\mathbf{F}_{1,t}$ can be obtained through the application of Principal Components Analysis (PCA) to the whole cross-country macro-financial data set $\mathbf{Z} = \{\mathbf{Z}_1, ..., \mathbf{Z}_T\}$ or, to enhance economic interpretability, on subsets of homogeneous cross-country data $\mathbf{Z}_i = \{\mathbf{Z}_{i,1}, ..., \mathbf{Z}_{i,T}\}$, $i = 1, ..., r_1$, $r_1 \leq q$; for instance, a GDP growth global factor can be estimated by means of the application of PCA to the vector of cross-country GDP growth data, a stock return global factor can be estimated through PCA applied to the vector of cross-country stock return data, and so on.

Then, conditional on the estimate of the unobserved stochastic factors, a preliminary estimate of the polynomial matrix $\mathbf{C}(L)$ and the factor loading matrix $\boldsymbol{\Lambda}$ is obtained by means of OLS estimation of the equation system in (9). This can be performed by first regressing $\hat{\mathbf{F}}_t$ on $\boldsymbol{\kappa}_t$ to obtain $\hat{\boldsymbol{\kappa}}_t$; then the actual series $\mathbf{Z}_t$ are regressed on $\boldsymbol{\mu}_t$ and $\hat{\mathbf{F}}_t - \hat{\boldsymbol{\kappa}}_t$ to obtain $\hat{\boldsymbol{\Lambda}}$ and $\hat{\boldsymbol{\mu}}_t$; $\hat{\mathbf{C}}(L)$ is then obtained by means of OLS estimation of the VAR model for the gap variables $\mathbf{Z}_t - \hat{\boldsymbol{\mu}}_t - \hat{\boldsymbol{\Lambda}}\left(\hat{\mathbf{F}}_t - \hat{\boldsymbol{\kappa}}_t\right)$ in (9).

- **Step 2: the iterative procedure.**

Next, a new estimate of the unobserved common factors in $\mathbf{F}_{1,t}$ can be obtained by means of PCA applied to the filtered variables $\mathbf{Z}_t^* = \mathbf{Z}_t - \left[\mathbf{I} - \hat{\mathbf{C}}(L)\right]\hat{\boldsymbol{\Lambda}}_*\left(\hat{\mathbf{F}}_{*,t} - \hat{\boldsymbol{\kappa}}_{*,t}\right)$, with $\hat{\mathbf{F}}_{*,t} = \left[\mathbf{F}'_{2,t}\ \mathbf{O}'_t\right]'$, $\hat{\boldsymbol{\Lambda}}_* = \left[\hat{\boldsymbol{\Lambda}}'_{F_2}\ \hat{\boldsymbol{\Lambda}}'_O\right]'$ and $\hat{\boldsymbol{\kappa}}_{*,t} = \left[\hat{\boldsymbol{\kappa}}'_{F_2,t}\ \hat{\boldsymbol{\kappa}}'_{O,t}\right]'$. Then, conditional on the new unobserved common factors, a new estimate of the polynomial matrix $\mathbf{C}(L)$ and the factor loading matrix $\boldsymbol{\Lambda}$ is attained as above described. The procedure is then iterated until convergence. Note that the proposed iterative procedure bears the interpretation of QML estimation performed by means of the EM algorithm. In the E-step the unobserved factors are estimated, given the observed data and the current estimate of model parameters, by means of PCA; in the M-step the likelihood function is maximized (OLS estimation of the $C(L)$ matrix is performed) under the assumption that the unobserved factors are known, conditioning on their E-step estimate. Convergence to the one-step QML estimate is ensured, as the value of the likelihood function is increased at each step. See Morana (2011a) for additional details on the asymptotic properties of the iterative estimation procedure.

- **Step 3: restricted estimation of the reduced form VAR model.**

Once the final estimates of the unobserved factors $\mathbf{F}_{1,t}$ are available the polynomial matrix $\mathbf{P}(L)$ in (12) can be consistently estimated by various approaches, i.e. OLS estimation of an asymmetric or asymmetric VAR model, or of a symmetric restricted VAR (PC-VAR), as proposed and implemented in the current paper; then, by employing $\hat{\mathbf{P}}(L)$ and the final estimate of the $\mathbf{C}(L)$ and $\boldsymbol{\Lambda}$ matrices, the $\boldsymbol{\Phi}^*(L)$ polynomial matrix is estimated as $\hat{\boldsymbol{\Phi}}^*(L) = \left[\hat{\boldsymbol{\Lambda}}\hat{\mathbf{P}}(L) - \hat{\mathbf{C}}(L)\hat{\boldsymbol{\Lambda}}\right]$.

9.1.1 PC-VAR estimation

PC-VAR estimation of $\mathbf{P}(L)$ relies on a second round implementation of PCA on the global variables $\hat{\mathbf{F}}_t$. The rationale for the second-round application of PCA is different from the one justifying the first-round one. While the aim of the first-round application of PCA is estimating the unobserved global factors, the second round application aims at a parsimonious description of the information contained in the estimated ($\mathbf{F}_{1,t}$) and observed ($\mathbf{F}_{2,t}$, $\mathbf{O}_t$) global factors, in order to lessen the curse of dimensionality affecting the estimation of symmetric VAR models in samples.

Then, following Morana (2011b) given the $r \times 1$ vector $\mathbf{x}_t \equiv \hat{\mathbf{F}}_t - \hat{\boldsymbol{\kappa}}_t$, consider the vector autoregressive (VAR) model in (7).

PC-VAR estimation relies on the following identity

$$\mathbf{x}_t \equiv \hat{\boldsymbol{\Xi}}\hat{\mathbf{f}}_t, \tag{13}$$

where $\hat{\mathbf{f}}_t = \hat{\boldsymbol{\Xi}}'\mathbf{x}_t$ is the $r \times 1$ vector of estimated principal components of $\mathbf{x}_t$, $\hat{\boldsymbol{\Xi}}$ is the $r \times r$ matrix of orthogonal eigenvectors associated with the r (ordered) eigenvalues of $\hat{\boldsymbol{\Sigma}}$ ($\boldsymbol{\Sigma} = E\left[\mathbf{x}_t\mathbf{x}_t'\right]$). This follows from the eigenvalue-eigenvector decomposition of $\hat{\boldsymbol{\Sigma}}$, i.e. $\hat{\boldsymbol{\Xi}}^{-1}\hat{\boldsymbol{\Sigma}}\hat{\boldsymbol{\Xi}} = \hat{\boldsymbol{\Gamma}}$, where $\hat{\boldsymbol{\Gamma}} = diag(\hat{\gamma}_1, ..., \hat{\gamma}_r)$ is the $r \times r$ diagonal matrix containing the (ordered) eigenvalues of $\hat{\boldsymbol{\Sigma}}$.

PC-VAR estimation of $\mathbf{P}(L)$ would then be implemented as follows:

- apply PCA to $\mathbf{x}_t$ and compute $\hat{\mathbf{f}}_t = \hat{\boldsymbol{\Xi}}'\mathbf{x}_t$;
- obtain $\hat{\mathbf{D}}(L)$ by means of OLS estimation of the stationary dynamic vector regression model

$$\begin{aligned} \mathbf{x}_t &= \mathbf{D}(L)\hat{\mathbf{f}}_t + \boldsymbol{\varepsilon}_t \\ \boldsymbol{\varepsilon}_t &\sim i.i.d.\left(\mathbf{0}, \boldsymbol{\Sigma}_{\varepsilon}\right), \end{aligned} \tag{14}$$

where $\mathbf{D}(L) \equiv \mathbf{D}_1 L + \mathbf{D}_2 L^2 + ... + \mathbf{D}_p L^p$ features all the roots outside the unit circle;

- recover the (implied OLS) estimate of the actual parameters yield by the symmetric VAR model in (7) by solving the linear constraints

$$\hat{\mathbf{P}}(L)_{PCVAR} = \hat{\mathbf{D}}(L)\hat{\boldsymbol{\Xi}}'.$$

Note that, by construction, the PC-VAR estimator and the OLS estimator of the symmetric VAR model in (7) are the same estimator, i.e.

$$\hat{\mathbf{P}}(L)_{OLS} = \hat{\mathbf{P}}(L)_{PCVAR}.$$

In fact, substituting (13) in (7) yields

$$\mathbf{x}_t = \mathbf{P}(L)\hat{\boldsymbol{\Xi}}\hat{\mathbf{f}}_t + \boldsymbol{\eta}_t \tag{15}$$

i.e. the dynamic vector regression in (14), with $\mathbf{D}(L) = \mathbf{P}(L)\hat{\boldsymbol{\Xi}}$ and $\boldsymbol{\eta}_t = \boldsymbol{\varepsilon}_t$.

The implied $\mathbf{P}(L)$ matrix is then estimated by computing

$$\begin{aligned} \hat{\mathbf{D}}(L)\hat{\boldsymbol{\Xi}}' &= \hat{\mathbf{P}}(L)\hat{\boldsymbol{\Xi}}\hat{\boldsymbol{\Xi}}' \\ &= \hat{\mathbf{P}}(L), \end{aligned}$$

as $\hat{\boldsymbol{\Xi}}\hat{\boldsymbol{\Xi}}' = \mathbf{I}_r$ due to the orthonormality of the eigenvectors. The PC-VAR estimator would therefore show the same asymptotic properties of the OLS estimator.

The case considered is however of no interest for empirical implementations, as it does not allow for any dimensionality reduction, relatively to the estimation of the symmetric VAR model.

The unfeasible case Consider the case in which only the first s, $s < r$, principal components associated with the s largest ordered eigenvalues of $\hat{\boldsymbol{\Sigma}}$ are considered, with $\hat{\gamma}_j = 0$, $j = s+1, ..., r$. The same results as obtained above ($s = r$, implicitly) would hold.

Rewrite the identity in (13) as

$$\begin{aligned} \mathbf{x}_t &= \hat{\boldsymbol{\Xi}}_s \hat{\mathbf{f}}_{s,t} + \hat{\boldsymbol{\Xi}}_{r-s} \hat{\mathbf{f}}_{r-s,t} && (16)\\ &= \mathbf{x}_{*,t} + \boldsymbol{\tau}_t \\ &= \mathbf{x}_{*,t} && (17) \end{aligned}$$

where $\underset{(r\times 1)}{\hat{\mathbf{f}}_t} = \begin{bmatrix} \underset{(1\times s)}{\hat{\mathbf{f}}'_{s,t}} & \underset{(1\times(r-s))}{\hat{\mathbf{f}}'_{r-s,t}} \end{bmatrix}'$, $\underset{(r\times r)}{\hat{\boldsymbol{\Xi}}} = \begin{bmatrix} \underset{(r\times s)}{\hat{\boldsymbol{\Xi}}_s} & \underset{(r\times r-s)}{\hat{\boldsymbol{\Xi}}_{r-s}} \end{bmatrix}$, $\mathbf{x}_{*,t} \equiv \hat{\boldsymbol{\Xi}}_s \hat{\mathbf{f}}_{s,t}$, $\boldsymbol{\tau}_t \equiv \hat{\boldsymbol{\Xi}}_{r-s} \hat{\mathbf{f}}_{r-s,t} = \mathbf{0}$ as $\hat{\mathbf{f}}_{r-s,t} = \mathbf{0}$.

Then, substituting (16) in (7) yields

$$\begin{aligned} \mathbf{x}_t &= \mathbf{P}(L)\left(\mathbf{x}_{*,t} + \boldsymbol{\tau}_t\right) + \boldsymbol{\eta}_t && (18)\\ &= \mathbf{P}(L)\mathbf{x}_{*,t} + \boldsymbol{\eta}_t. \end{aligned}$$

PC-VAR would then entail OLS estimation of

$$\begin{aligned} \mathbf{x}_t &= \mathbf{D}(L)\hat{\mathbf{f}}_{s,t} + \boldsymbol{\varepsilon}_t && (19)\\ \boldsymbol{\varepsilon}_t &\sim i.i.d.\left(\mathbf{0}, \boldsymbol{\Sigma}_{\boldsymbol{\varepsilon}}\right). \end{aligned}$$

Then, by writing $\mathbf{D}_*(L) \equiv \mathbf{D}_{*1}L + \mathbf{D}_{*2}L^2 + ... + \mathbf{D}_{*p}L^p$, with $\mathbf{D}_{*j}(L) = \begin{bmatrix} \underset{(r\times s)}{\mathbf{D}_j(L)} & \underset{(r\times r-s)}{\mathbf{0}} \end{bmatrix}$, $j = 1, ..., p$, and $\mathbf{P}_*(L) \equiv \mathbf{P}_{1*}L + \mathbf{P}_{2*}L^2 + ... + \mathbf{P}_{p*}L^p$, with $\mathbf{P}_{*j} = \begin{bmatrix} \underset{(r\times s)}{\mathbf{P}_j\hat{\boldsymbol{\Xi}}_s} & \underset{(r\times r-s)}{\mathbf{0}} \end{bmatrix} = \begin{bmatrix} \underset{(r\times r)}{\mathbf{P}_j} & \underset{(r\times r-s)}{\mathbf{0}} \end{bmatrix} \odot \hat{\boldsymbol{\Xi}}$, $j = 1, ..., p$, and where $\odot$ is the Hadamart product, it follows that

$$\begin{aligned}\hat{\mathbf{D}}_*(L)\hat{\boldsymbol{\Xi}}' &= \hat{\mathbf{P}}_*(L)\hat{\boldsymbol{\Xi}}' \\ &= \hat{\mathbf{P}}(L)\odot\hat{\boldsymbol{\Xi}}\,\hat{\boldsymbol{\Xi}}' \\ &= \hat{\mathbf{P}}(L),\end{aligned}$$

That is,

$$\hat{\mathbf{P}}(L)_{PCVAR} = \hat{\mathbf{D}}_*(L)\hat{\boldsymbol{\Xi}}' = \hat{\mathbf{D}}(L)\hat{\boldsymbol{\Xi}}_s'. \tag{20}$$

The feasible case Consider the case in which only the first s, $s < r$, principal components associated with the s largest ordered eigenvalues of $\hat{\boldsymbol{\Sigma}}$ are considered and $\gamma_j \simeq 0$, $j = s+1, ..., r$.

Consistency of the PC-VAR estimator in (20)

$$\hat{\mathbf{P}}(L)_{PCVAR} = \hat{\mathbf{D}}(L)\hat{\boldsymbol{\Xi}}_s',$$

obtained from OLS estimation of (19), can then be established.

In fact, by rewriting (18) as

$$\begin{aligned}\mathbf{x}_t &= \mathbf{P}(L)\mathbf{x}_{*,t} + \mathbf{P}(L)\boldsymbol{\tau}_t + \boldsymbol{\eta}_t && (21)\\ &= \mathbf{P}(L)\hat{\boldsymbol{\Xi}}_s\hat{\mathbf{f}}_{s,t} + \mathbf{P}(L)\hat{\boldsymbol{\Xi}}_{r-s}\hat{\mathbf{f}}_{r-s,t} + \boldsymbol{\eta}_t \\ &= \mathbf{P}(L)\hat{\boldsymbol{\Xi}}_s\hat{\mathbf{f}}_{s,t} + \boldsymbol{\vartheta}_t, && (22)\end{aligned}$$

where $\boldsymbol{\vartheta}_t = \boldsymbol{\eta}_t + \mathbf{P}(L)\boldsymbol{\tau}_t \simeq \boldsymbol{\eta}_t$, as, for $\gamma_j \to 0$, $\hat{\mathbf{f}}_{r-s,t} \to \mathbf{0}$.

Consistency of the PC-VAR estimator $\hat{\mathbf{D}}(L)\hat{\boldsymbol{\Xi}}_s'$ depends on the limiting contemporaneous uncorrelation condition $plim\left(\dfrac{\hat{\mathbf{f}}_s'\boldsymbol{\vartheta}}{T}\right) = \mathbf{0}$ being satisfied, where $\hat{\mathbf{f}}_s = \begin{bmatrix} \hat{\mathbf{f}}_{s,-1} & ... & \hat{\mathbf{f}}_{s,-p} \end{bmatrix}$ is the $T \times (s \times p)$ design matrix containing the temporal information on the lagged principal components and $\boldsymbol{\vartheta}$ is the $T \times 1$ vector containing the temporal information on the error process. The latter condition would necessarily hold for the $p = 1$ case, as $plim\left(\dfrac{\mathbf{x}_{*,t-1}\boldsymbol{\tau}_{t-1}}{T}\right) = \mathbf{0}$ by construction, due to the orthogonality of $\hat{\mathbf{f}}_{s,t}$ and $\hat{\mathbf{f}}_{r-s,t}$, and therefore of $\mathbf{x}_{*,t}$ and $\boldsymbol{\tau}_t$. For the $p > 1$ case, the condition $plim\left(\dfrac{\mathbf{x}_{*,t-i}\boldsymbol{\tau}_{t-j}}{T}\right) = \mathbf{0}$, $i, j = 1, ..., p$, $i \neq j$, would appear to be required. As under the weak stationarity assumption, for any generic element in the $\mathbf{x}_{*,t}$ and $\boldsymbol{\tau}_t$ vectors, the Wold decomposition would yield

$$\begin{aligned} x_{*m,t-i} &= \gamma(L)\varepsilon_{x_{*,m},t-i} \qquad m = 1, ..., s \\ \varepsilon_{x_{*,m},t} &\sim i.i.d.\left(0, \sigma^2_{\varepsilon_{x_{*,m}}}\right) \end{aligned}$$

$$\begin{aligned} \tau_{*n,t-j} &= \theta(L)\varepsilon_{\tau_n,t-j} \qquad n = 1, ..., r-s \\ \varepsilon_{\tau_n,t} &\sim i.i.d.\left(0, \sigma^2_{\tau_n}\right), \end{aligned}$$

with $\gamma(L)$ and $\theta(L)$ stationary infinite order polynomials in the lag operator, provided $E\left[\varepsilon_{x_{*,m},t}\varepsilon_{\tau_n,t}\right] = 0$, the necessary conditions for consistency would then be satisfied; the latter requirement it appears to be not restrictive. Asymptotic Normality also follows under the same conditions of validity for the OLS estimator.

Monte Carlo results (see the Appendix) strongly support the PC-VAR estimation strategy, showing that the suggested procedure may yield gains, in terms of both lower bias and higher efficiency, over unrestricted OLS VAR estimation. Selecting the number of principal components (s) such that the proportion of total variance accounted for is in the range 80% to 90% would be advisable for empirical applications in general.

9.1.2 Reduced form vector moving average representation of the F-VAR model

By inverting the VAR model in (12), the reduced form VMA representation is obtained; this yields

$$\mathbf{Y}_t - \boldsymbol{\gamma}_t = \mathbf{H}(L)\boldsymbol{\varepsilon}_t, \tag{23}$$

where $\mathbf{H}(L) \equiv (\mathbf{I} - \mathbf{A}(L))^{-1}$.

By partitioning $\mathbf{H}(L)$ according to the block diagonal structure of (12), i.e. $\mathbf{H}(L) \equiv \begin{pmatrix} \mathbf{H}_F(L) & \mathbf{0} \\ \mathbf{H}_{FZ}(L) & \mathbf{H}_Z(L) \end{pmatrix}$, the VMA representation in (23) can then be written

$$\begin{pmatrix} \mathbf{F}_t - \boldsymbol{\kappa}_t \\ \mathbf{Z}_t - \boldsymbol{\mu}_t \end{pmatrix} = \begin{pmatrix} \mathbf{H}_F(L) & \mathbf{0} \\ \mathbf{H}_{FZ}(L) & \mathbf{H}_Z(L) \end{pmatrix} \begin{pmatrix} \boldsymbol{\varepsilon}_{1,t} \\ \boldsymbol{\varepsilon}_{2,t} \end{pmatrix}. \tag{24}$$

9.1.3 Structural vector moving average representation of the F-VAR model

The identification of the structural shocks can be achieved through the following double-Choleski strategy.

Denoting by $\boldsymbol{\xi}_t$ the vector of the r structural shocks driving the common factors in $\mathbf{F}_t$, the relation between the reduced form and the structural factor disturbances can be written as $\boldsymbol{\xi}_t = \mathbf{K}\,\boldsymbol{\eta}_t$, where $\mathbf{K}$ is a $r \times r$ invertible matrix. By assumption the structural factor shocks are orthogonal and have unit variance, so that $E\left[\boldsymbol{\xi}_t\boldsymbol{\xi}_t'\right] = \mathbf{K}\,\boldsymbol{\Sigma}_\eta\,\mathbf{K}' = \mathbf{I}_r$. To achieve exact identification of the structural disturbances, additional $r(r-1)/2$ restrictions need to be imposed. Since $\boldsymbol{\eta}_t = \mathbf{K}^{-1}\boldsymbol{\xi}_t$, imposing exclusion restrictions on the contemporaneous impact matrix amounts to imposing zero restrictions on the elements of $\mathbf{K}^{-1}$, for which a lower-triangular structure is assumed. This latter assumption implies a precise "ordering" of the common factors in $\mathbf{F}_t$. In particular, the first factor is allowed to have a contemporaneous impact on all other factors, but reacts only with a one-period lag to the other structural disturbances; instead, the last factor is contemporaneously affected by all structural shocks, having only lagged effects on all other factors. Operationally, $\mathbf{K}^{-1}$ (with the $r(r-1)/2$ zero restrictions necessary for exact identification imposed) is estimated by the Choleski decomposition of the factor innovation variance-covariance matrix $\boldsymbol{\Sigma}_\eta$, i.e. $\hat{\mathbf{K}}^{-1} = chol(\hat{\boldsymbol{\Sigma}}_\eta)$.

A similar procedure is applied to obtain the identification of the idiosyncratic structural shocks driving the innovations in $\mathbf{v}_t$, which can be estimated by regressing $\hat{\boldsymbol{\varepsilon}}_{2,t}$ on $\hat{\boldsymbol{\eta}}_t$ by OLS, yielding $\hat{\mathbf{v}}_t$ as the residuals. Denoting by $\boldsymbol{\upsilon}_t$ the vector of n structural idiosyncratic shocks (uncorrelated with the $\boldsymbol{\xi}_t$ shocks), the relation between the reduced form and the structural idiosyncratic disturbances can be written as $\boldsymbol{\upsilon}_t = \mathbf{G}\,\mathbf{v}_t$, where $\mathbf{G}$ is a $n \times n$ invertible matrix. In addition to the orthogonality conditions $E\left[\boldsymbol{\upsilon}_t\boldsymbol{\upsilon}_t'\right] = \mathbf{G}\boldsymbol{\Sigma}_v'\mathbf{G}' = \mathbf{I}_n$, $n(n-1)/2$ zero restrictions are needed for exact identification. Since $\mathbf{v}_t = \mathbf{G}^{-1}\boldsymbol{\upsilon}_t$, the required restrictions can be imposed by assuming a lower-triangular structure for the contemporaneous impact matrix $\mathbf{G}^{-1}$. Operationally, also $\mathbf{G}^{-1}$ is then estimated by the Choleski decomposition of the idiosyncratic innovation variance-covariance matrix $\boldsymbol{\Sigma}_v$, i.e. $\hat{\mathbf{G}}^{-1} = chol(\hat{\boldsymbol{\Sigma}}_v)$.

The structural VMA representation can then be written as

$$\begin{pmatrix} \mathbf{F}_t - \boldsymbol{\kappa}_t \\ \mathbf{Z}_t - \boldsymbol{\mu}_t \end{pmatrix} = \begin{pmatrix} \mathbf{H}_F(L)\mathbf{K}^{-1} & \mathbf{0} \\ \mathbf{H}_{FZ}(L)\mathbf{K}^{-1} & \mathbf{H}_Z(L)\mathbf{G}^{-1} \end{pmatrix} \begin{pmatrix} \boldsymbol{\xi}_t \\ \boldsymbol{\upsilon}_t \end{pmatrix}. \tag{25}$$

Forecast error variance and historical decompositions can then be obtained by means of standard formulas.

Following the thick modelling strategy of Granger and Jeon (2004), median estimates of the parameters of interest, impulse responses, forecast error variance and historical decompositions, as well as of their confidence intervals, robust to model misspecification, can be obtained by means of simulated implementation of the proposed estimation strategy.

9.1.4 PC-VAR: Monte Carlo results

Consider the following data generation process (DGP) for the $n \times 1$ vector process $\mathbf{x}_t$

$$\begin{aligned} \mathbf{\Phi}(L)\,\mathbf{x}_t &= \mathbf{v}_t \\ \mathbf{v}_t &\sim n.i.d.(\mathbf{0}, \mathbf{\Sigma}_v), \end{aligned} \tag{26}$$

where $n = 25$, $\mathbf{\Phi}(L) = diag\begin{pmatrix} \phi_1(L) & \dots & \phi_n(L) \end{pmatrix}$, with

i) $\phi_i(L) = 1 - 0.4L$, $i = 1, ..., n$, for the first order case;

ii) $\phi_i(L) = 1 - 0.4L - 0.2L^2$, $i = 1, ..., n$, for the second order case;

iii) $\phi_i(L) = 1 - 0.4L - 0.2L^2 + 0.2L^3$, $i = 1, ..., n$, for the third order case;

iv) $\phi_i(L) = 1 - 0.4L - 0.2L^2 + 0.2L^3 - 0.1L^4$, $i = 1, ..., n$, for the fourth order case;

$$\mathbf{\Sigma}_v = \begin{bmatrix} 1 & \rho & \cdots & \rho \\ \rho & 1 & \ddots & \vdots \\ \vdots & \vdots & \ddots & \rho \\ \rho & \cdots & \rho & 1 \end{bmatrix}, \text{ with } \rho = \{0, 0.3, 0.6, 0.9\}.$$

The estimated models are the PC-VAR(p,r) model, considering r principal components, $r = 2, 4, ..., 24$ and $p = 1, .., 4$ lags, and the unrestricted VAR(p) model, equivalent to the PC-VAR(p,r) model with $r = n$ (25). The temporal (usable) sample size is $T = 100$ and the number of replications is 500.

The results of the Monte Carlo analysis are reported in Table A1. In the table results at the system level only, i.e the mean absolute bias and the root mean square error, across parameters and equations, are reported.

As is shown in Table A1, PC-VAR estimation does allow to improve over unrestricted OLS VAR estimation, in terms of both lower bias and higher efficiency, independently of the order of the system and the strength of the contemporaneous cross-sectional correlation relating the error terms. By following a bias minimization criterion, two broad cases may however be distinguished, i.e. the non-correlated errors case ($\rho = 0$) and the correlated errors case ($\rho \geq 0.3$). For the former one, the required proportion of total variance to be explained (optimal number of principal components) ranges between about 50% and 90%, depending on the order of the system, falling as the order of the system increases. On the other hand, a tighter required explained variance interval can be found for the latter case, increasing with the strength of the cross-sectional correlation: 80% to 90% for the low correlation case ($\rho = 0.3$), 85% to 95% for the intermediate correlation case ($\rho = 0.6$), and 90% to 100% for the high correlation case ($\rho = 0.9$). Moreover, also for the correlation case the required proportion of explained variance tends to fall as the order of the system increases.

Overall, while the bias improvement is small, yet sizable (10% to 20%) for the VAR(1) and VAR(2) cases, for which the degrees of freedom are not smaller than 50% of the sample size, PC-VAR estimation yields a much more dramatic bias reduction (60% to 80%) for the VAR(3) and VAR(4) cases, as the degrees of freedom fall to 25% of the sample size and 0, respectively. Similarly concerning efficiency, as PC-VAR yields a RMSE reduction in the range 30% to 50% for the VAR(1) and VAR(2) case, and 60% to 90% for the VAR(3) and VAR (4) case.

Table A1: Monte Carlo results.

	# PC (explained total variance)												
ρ=0	**2**(.18)	**4**(.32)	**6**(.44)	**8**(.55)	**10**(.64)	**12**(.72)	**14**(.78)	**16**(.84)	**18**(.89)	**20**(.93)	**22**(.96)	**24**(.99)	**25**(1.0)
	PC-VAR(1)												***VAR(1)***
Bias	0.015	0.014	0.013	0.012	0.011	0.010	0.009	0.009	0.008	0.008	0.008	0.008	0.009
RMSE	0.054	0.064	0.069	0.072	0.075	0.078	0.082	0.085	0.090	0.096	0.104	0.114	0.120
	PC-VAR(2)												***VAR(2)***
Bias	0.012	0.011	0.010	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.010	0.010	0.011
RMSE	0.046	0.056	0.063	0.069	0.074	0.080	0.087	0.094	0.103	0.114	0.126	0.142	0.151
	PC-VAR(3)												***VAR(3)***
Bias	0.011	0.010	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.010	0.011	0.013	0.014
RMSE	0.044	0.054	0.062	0.069	0.076	0.084	0.094	0.105	0.119	0.136	0.158	0.187	0.208
	PC-VAR(4)												***VAR(4)***
Bias	0.009	0.009	0.008	0.008	0.008	0.008	0.009	0.009	0.010	0.012	0.015	0.019	0.027
RMSE	0.040	0.051	0.060	0.069	0.078	0.089	0.102	0.119	0.142	0.175	0.229	0.334	0.515

	# PC (explained total variance)												
ρ=0.3	**2**(.40)	**4**(.51)	**6**(.60)	**8**(.68)	**10**(.74)	**12**(.80)	**14**(.85)	**16**(.89)	**18**(.92)	**20**(.95)	**22**(.97)	**24**(.99)	**25**(1.0)
	PC-VAR(1)												***VAR(1)***
Bias	0.028	0.024	0.021	0.018	0.015	0.013	0.011	0.010	0.009	0.009	0.009	0.009	0.010
RMSE	0.053	0.064	0.071	0.076	0.080	0.085	0.090	0.096	0.102	0.111	0.120	0.132	0.140
	PC-VAR(2)												***VAR(2)***
Bias	0.021	0.018	0.015	0.013	0.012	0.010	0.010	0.010	0.010	0.010	0.010	0.011	0.012
RMSE	0.045	0.058	0.067	0.075	0.082	0.090	0.098	0.108	0.119	0.132	0.147	0.165	0.177
	PC-VAR(3)												***VAR(3)***
Bias	0.019	0.016	0.014	0.012	0.011	0.010	0.010	0.010	0.010	0.011	0.012	0.014	0.015
RMSE	0.042	0.055	0.065	0.075	0.084	0.095	0.107	0.120	0.137	0.158	0.184	0.219	0.242
	PC-VAR(4)												***VAR(4)***
Bias	0.016	0.014	0.012	0.010	0.010	0.009	0.009	0.010	0.011	0.013	0.016	0.021	0.030
RMSE	0.038	0.053	0.064	0.075	0.087	0.101	0.117	0.137	0.164	0.203	0.265	0.392	0.598

	# PC (explained total variance)												
ρ=0.6	**2**(.65)	**4**(.72)	**6**(.77)	**8**(.81)	**10**(.85)	**12**(.89)	**14**(.91)	**16**(.94)	**18**(.96)	**20**(.97)	**22**(.99)	**24**(1.0)	**25**(1.0)
	PC-VAR(1)												***VAR(1)***
Bias	0.028	0.024	0.021	0.018	0.015	0.013	0.012	0.011	0.010	0.010	0.010	0.010	0.011
RMSE	0.055	0.069	0.079	0.086	0.094	0.102	0.111	0.120	0.130	0.143	0.157	0.173	0.183
	PC-VAR(2)												***VAR(2)***
Bias	0.021	0.018	0.016	0.013	0.012	0.011	0.010	0.010	0.010	0.011	0.012	0.013	0.014
RMSE	0.049	0.066	0.079	0.090	0.100	0.112	0.124	0.137	0.152	0.170	0.191	0.216	0.231
	PC-VAR(3)												***VAR(3)***
Bias	0.019	0.016	0.014	0.012	0.011	0.011	0.011	0.011	0.011	0.013	0.014	0.016	0.018
RMSE	0.046	0.064	0.078	0.092	0.105	0.119	0.136	0.155	0.178	0.205	0.240	0.286	0.319
	PC-VAR(4)												***VAR(4)***
Bias	0.016	0.014	0.012	0.011	0.010	0.010	0.011	0.012	0.013	0.015	0.018	0.026	0.035
RMSE	0.043	0.062	0.078	0.094	0.109	0.129	0.151	0.179	0.216	0.267	0.347	0.511	0.774

	# PC (explained total variance)												
ρ=0.9	**2**(.91)	**4**(.93)	**6**(.94)	**8**(.95)	**10**(.96)	**12**(.97)	**14**(.98)	**16**(.98)	**18**(.99)	**20**(.99)	**22**(1.0)	**24**(1.0)	**25**(1.0)
	PC-VAR(1)												***VAR(1)***
Bias	0.028	0.024	0.021	0.018	0.017	0.014	0.013	0.014	0.014	0.014	0.016	0.016	0.017
RMSE	0.065	0.094	0.116	0.137	0.157	0.177	0.200	0.224	0.252	0.279	0.309	0.344	0.366
	PC-VAR(2)												***VAR(2)***
Bias	0.021	0.018	0.016	0.015	0.014	0.014	0.014	0.014	0.015	0.018	0.019	0.021	0.023
RMSE	0.067	0.105	0.133	0.158	0.183	0.210	0.238	0.267	0.299	0.337	0.378	0.426	0.457
	PC-VAR(3)												***VAR(3)***
Bias	0.019	0.016	0.015	0.015	0.015	0.014	0.015	0.014	0.015	0.018	0.019	0.022	0.025
RMSE	0.067	0.104	0.134	0.163	0.193	0.225	0.262	0.302	0.348	0.404	0.472	0.564	0.623
	PC-VAR(4)												***VAR(4)***
Bias	0.016	0.014	0.013	0.013	0.013	0.014	0.015	0.017	0.020	0.024	0.029	0.045	0.055
RMSE	0.066	0.107	0.141	0.172	0.206	0.244	0.289	0.347	0.419	0.527	0.683	1.037	1.434

The Table reports Monte Carlo (absolute) bias and RMSE statistics (average across parameters and equations), from PC-VAR and unrestricted OLS VAR estimation, of first, second, third, and fourth order systems, with residuals correlation coefficient $\boldsymbol{\rho}$ = (0, 0.3, 0.6, 0.9), temporal sample size $\boldsymbol{T}$ = 100, sectional sample size $\boldsymbol{n}$ = 25, and 500 replications. The estimated models are the PC-VAR model, considering *r* principal components, *r*=2,4,…,24, and the unrestricted VAR model, equivalent to the PC-VAR model with *r*=*n* (25) principal components.