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Abstract

The aim of this paper is to study the relationship between the effective exchange rate of the dollar and the oil price dynamics from 1976 to 2013. In this context, we propose to explore the economic literature dedicated to financial channels factors (exchange rate, monetary policy, and international liquidity) that could affect the oil price dynamics. In addition to oil prices and the effective exchange rate of the dollar, we use the dry cargo index as a proxy for the real economic activity and prices for precious and industrial raw materials. Using a Bayesian time-varying parameter vector auto-regressive estimation, our main results show that the US Dollar effective exchange rate elasticity of the crude oil prices is not constant across the time and remains negative from 1989. It then highlights that a depreciation of the effective exchange rate of the dollar leads to an increase of the crude oil prices. Our paper also demonstrates the growing influence of financial and commodities markets development upon the global economy.

1. Introduction

1.1 Context

The foreign exchange market and the oil markets have registered a strong increase in volatility since the 1970s. They have both experienced shocks and crises. With the abandonment of the gold to dollar linkage which led to the Jamaica agreement (1976), the world economy experienced a new financial context with the advent of a floating foreign exchange market. In the oil market the take-over of the OPEC countries in 1973-1974 can be considered as the starting point of a new context of instability compared to the previous decade. As oil is quoted in US dollars (USD), the oil price and the value of the dollar seem to have a mutual influence and it is relevant to study the interaction between those two variables. Several studies have previously investigated the link between the USD and the oil prices.

1.2 Literature Review

Regarding theoretical studies, Krugman (1980, 1983) analyses the variation of the USD following an oil price increase in a model with three different areas (America, Germany and the OPEC countries). He shows that the final effect on the Dollar exchange rate in the short run heavily depends on the comparison between the US weight in world oil imports and the share of Dollar assets in OPEC's portfolio; while in the long run, the comparison has to be made between the US share in world oil imports and the weight of US goods in OPEC's imports. Golub (1983), like Krugman, divides the world according to three areas (America, Europe and the OPEC countries) and two currencies (USD and Deutsche Mark) and focuses on the wealth transfers of the OPEC countries. Under the assumption of inelastic demand of oil from Europe and America, the American currency will depreciate against the German currency if the OPEC countries have a higher propensity to hold marks than the oil-importing countries. If, as a result of the transfer of wealth, there is an excess demand for Deutsche Mark, then the dollar exchange rate will depreciate.

Turning to empirical studies, no clear consensus exists in the literature concerning both the direction and the sign of the relationship between oil price and the value of the Dollar (e.g., Beckmann and Czudaj (2013)). As regards to the direction of the relationship, some studies mainly focused on the oil price to exchange rate causality. For instance, Chen and Chen (2007) investigate the long-term relationship between the real oil prices and the real exchange rate. Using a panel data methodology, they find a cointegration relationship using a set of different markers of crude oil or basket price (Brent, Dubai, West Texas Intermediate (WTI) and world prices), and conclude that the oil prices are "the dominant source of real exchange rate movements". However, some studies such as Sadorsky (2000) and Krichene (2007) found a reverse causality from USD to oil prices. Therefore, the direction of the causality between oil price and exchange rate is not clear cut. Percebois (2009) summarizes the complexity of the relationship by emphasizing the possibility of a bilateral causality through various macroeconomic channels such as: the effect on world demand through local prices, a Chinese effect, an effect due to the petrodollar recycling effect, and a target revenue effect. Bénassy-Quéré and al. (2007) highlight the existence of a cointegration relationship between the oil price and the Dollar real effective exchange rate for the 1974-2004 periods with the causality link running from oil price to the exchange rate. Nevertheless, the authors suggest that the causality link could be reversed in the 2002-2004 period because of the Chinese monetary policy. Benhmad (2012), using wavelet analysis, emphasized also that time scales matter. Causality between real oil price and real effective US Dollar exchange rate returns runs in bidirectional ways in long time horizons, while in short time horizons, causality runs from oil prices to real effective US Dollar exchange rate returns.

As regards to the sign of the relationship, there is also no clear consensus in the empirical literature. Amano and Van Norden (1998a, 1998b) show that the impact of an oil price increase on the exchange rate is heterogeneous across countries: a 10 percent increase in the oil price leads to a depreciation of both Japanese and German currencies (respectively of 1.7 and 0.9 percent), when it causes an appreciation of the USD of around 2.4 percent. Relying on two monetary models (Basic and Composite Models), Lizardo and Mollick (2010) highlight that dependency to oil could play a role in the relationship. They split the countries panel into two groups (net importers and net exporters of crude oil). They show for the oil exporters countries that in most of the cases, an increase in the oil price is followed by an appreciation of their currencies relative to the USD, while for the oil importers countries, their currencies tend to decrease relatively to the USD. Reboredo et al. (2014) study the relationship between WTI price and the exchange rate of US Dollar against a set of currencies[1], splitting the period of studies into two samples: one before the crisis (July 2008), and one after. The author find that the cross-correlations between oil-price and exchange rates are negative and that dependence increase after the start of the financial crisis. Finally, with an analysis based on impulse responses and forecast error variance decomposition, Akram (2009) focuses on the relationship between oil prices, commodity prices, the USD exchange rate, the global output and interest rates. Building three VAR models, he argues that a positive shock on the oil price is followed by real exchange rate depreciation, while a real exchange rate depreciation leads to higher commodity prices (including oil prices).

Thus, it seems obvious that there is no clear-cut result regarding neither the direction of the relationship between exchange rate and oil price, nor the extent of the elasticity due essentially to different sample period considered in the previous listed studies. In our paper, we try to solve it with an innovative methodology. To improve the comprehension of the oil price-exchange rate relationship, we use time-varying Bayesian VAR to estimate the different parameters of interest. This methodology offers three main advantages in our analysis. First, as a VAR analysis, it takes into account endogeneity among the set of variables and, thus, permits to circumvent the absence of consensus concerning the direction of the relationship. Second, the estimated elasticities, which measure the movement in percentage of the variables of interest following one percent change of one variable, evolve through the whole estimation period, enlarging the scope of the interpretation (in terms of magnitude and periodicity) compared to previous empirical studies. Third, it permits to model both abrupt break and persistence in the relationship between variables of interest. Indeed, relationship between oil price and exchange rate might be subject to structural break due to different exogenous oil events such as war, OPEC decisions, economic policy changes, etc. It might also be subject to gradual evolution due to

[1] Respectively the Australian Dollar, the Canadian Dollar, the Japanese Yen, the Mexican Peso, the Euro, the Norwegian Krone and the British Pound.

adaptative learning behaviour of agents (Primiceri, 2005). Therefore, letting data determine either the relationship presents a break or is persistent is a valuable future of this methodology. Fourth, the Forecast Error Variance Decomposition (henceforth FEDV) which measures the contribution of different variables in the model to the volatility of the variable of interest is calculated for the entire period of the sample. Up to our knowledge, this paper is the first one that uses the time-varying FEDV for the oil prices-exchange rate analysis and, hence, contributes to a more comprehensive analysis of this subject with regards to time-changing economic environment pattern and monetary policy during the estimation period.

We use monthly data on oil price (Spot market Brent price expressed in US dollars)[2], the gold price (spot price in the London Commodity Exchange measured in US dollars), the effective exchange rate of the Dollar, the HWWI index[3] (Industrial raw materials measured in US dollars) and the dry cargo index as a proxy for the real economic activity. Our monthly data cover the sample period from 1976:07 to 2013:07. Oil and gold prices are extracted from Datastream database (respectively, with code "UKI..C..A" and "UKOILBREN"). The US Dollar effective exchange rate we use is the nominal major currencies Dollar index extracted from the board of governors of the Federal Reserve System (Foreign Exchange Rates - H.10). Finally, the Dry Cargo index is available at Lutz Kilian personal webpage. Except for Dry cargo index, all variables are rendered stationary by taking the first difference of their natural logarithm. The rest of the paper is organized as follows: Section 2 is dedicated to the model specification, empirical results are provided in Section 3 and Section 4 concludes the article.

2. Model specification

2.1 Time-varying parameters

To highlight the influence of the effective exchange rate of the USD on oil prices during the whole estimation period, we use the Bayesian time-varying VAR estimation approach. There are several reasons why the link between variables considered in our studies is likely to be time varying. First, foreign exchange market and the oil markets have registered a strong increase in volatility since 1970s whereas real economic activity encountered a significant decrease in volatility during the great moderation. Second, literature on oil prices such as Kilian (2009) argued that shocks underlying oil price fluctuations come from different sources such as oil supply disruption and physical or precautionary oil demand surge. Thus, given that the different natures of oil price shocks generally occur at different periods, link between oil price and other variables is likely to change over time. Third, the growing financialisation of commodities markets since 2000 indeed changes the link between oil prices and other commodities prices.

Starting from the state-space representation of the reduced form of the VAR model, the entire sequence of the time varying regression parameters and their

[2] We use Brent Price in this article instead of WTI or OPEC basket price because Brent helps to price around 70% of the global oil transactions. In addition we consider that WTI has, since the last decade, a very specific history and tends to disconnect from the international oil market.

[3] See Box 1 in Appendix A for a more accurate decomposition of the HWWI Index.

respective variances are generated via forward and backward recursion of Kalman filter, thus using all the information available throughout the entire estimation period. The entire sequences of parameters of interest are estimated by simulating their distribution using Bayesian approach, namely we implement a Gibbs sampler. Details of the estimation procedure are available in the appendix[4].

2.1.1 The model

Consider the following structural VAR representation of a multivariate time series model with both time-varying coefficients, contemporaneous and lagged, and time-varying standard-error of structural innovations:

$$B_t Y_t = d_t + C_{1,t} Y_{t-1} + \cdots + C_{p,t} Y_{t-p} + \Sigma_t \upsilon_t \tag{1}$$

where $Y_t = [Y'_{1t}, Y'_{2t}, \ldots, Y'_{nt}]'$ is a vector of *n* endogenous variables, $d_t = [d'_{1t}, d'_{2t}, \ldots, d'_{nt}]'$ is a vector of *n* time-varying constants, C_{pt} is the matrix of time-varying lag coefficients of the structural model and υ_t is a vector of structural innovations which is assumed to follow a multivariate normal distribution,

$$\upsilon_t \rightsquigarrow \mathcal{N}(\mathbf{0}, \mathbf{I}_n)$$

Using AIC, BIC and HQ information criterions, we retain one lag for the estimation. Indeed, changes in the relationship between variables in the model can be the result of changes in the contemporaneous relationship B_t between variables, changes in the propagation mechanism C_{pt} and changes in the size of the standard error of innovations Σ_t. Therefore, allowing parameters of interest to vary over time leaves it up to the data to determine the nature and the time-varying evolution of this relationship.

Moreover, we assume that the matrix of time-varying contemporaneous coefficients B_t is lower triangular with ones along its diagonal elements

$$B_t = \begin{pmatrix} 1 & 0 & \cdots & \cdots & 0 \\ b_{21,t} & 1 & 0 & \cdots & 0 \\ b_{31,t} & b_{32,t} & 1 & \ddots & \vdots \\ \vdots & \vdots & \ddots & \ddots & 0 \\ b_{n1,t} & b_{n2,t} & \cdots & b_{nn-1,t} & 1 \end{pmatrix}$$

whereas the matrix of time-varying standard-error Σ_t is diagonal.

[4] Our methodology draws on that of Cogley and Sargent (2005), and Primiceri (2005) with some modifications.

$$\Sigma_t = \begin{pmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{n,t} \end{pmatrix}$$

For estimation purpose, reduced form representation of the structural model (1) is given by:

$$Y_t = c_t + A_{1,t}Y_{t-1} + \cdots + A_{p,t}Y_{t-p} + \epsilon_t \quad (2)$$

where $A_{p,t} = B_t^{-1}C_{p,t}$ are the matrices of lag-coefficients, $c_t = B_t^{-1}d_t$ is the vector of constants and $\epsilon_t = B_t^{-1}\Sigma_t \upsilon_t$ is the vector of reduced-form residuals. Following the structure of the contemporaneous coefficients matrix B_t and that of the standard error of the structural innovations matrix $\sum_t$, we can assume that reduced-form residuals have the following structure:

$$\epsilon_t \rightsquigarrow \mathcal{N}(\mathbf{0}, \Omega_t)$$

where Ω_t is a symmetric and positive definite time-varying variance-covariance matrix of ϵ_t that verifies the following equality,

$$B_t\Omega_t B_t' = \Sigma_t\Sigma_t' \quad (3)$$

It is worth noting that this structure implies a Cholesky identification scheme restricting the matrix of contemporaneous relationship to be lower triangular. Thus, the order of variables in the reduced-form representation (2) matters[5]. However, after estimating the model, it is possible to choose a decomposition of Ω_t satisfying $S_t S_t' = \Omega_t$ allowing for richer identification strategies.

Time paths for parameters of interest are assumed to be random walks without drifts[6]. If we denote α_t the vector column that contains stacked columns of matrix A_t, $b_t = \left(b_{21,t}\; b_{31,t}\; b_{32,t}\; \cdots\; b_{nn-1,t}\right)'$ the vector column that contains the elements of the matrix of contemporaneous relationship, B_t, $\sigma_t = \left(\sigma_{1,t} \cdots \sigma_{n,t}\right)'$ the vector column that contains the diagonal elements of the matrix of standard error Σ_t and $h_t = ln(\sigma_t)$ the natural logarithm of the standard error, parameters evolve according to

[5] As explained in Primiceri (2005), if one is particularly concerned about this problem, a natural solution is to impose a prior on all plausible orders of the variables and, after estimation, average on the basis of the prior or the posterior of different models.

[6] Even though the dynamics of the parameters can be easily extended to a more general autoregressive process, we assume random walk process in order to focus on possible permanent shifts and to reduce the number of parameters in the estimation procedure.

$$\begin{aligned} \alpha_t &= \alpha_{t-1} + \omega_t \\ b_t &= b_{t-1} + \zeta_t \\ h_t &= h_{t-1} + \eta_t \end{aligned} \tag{5}$$

This random walk specification has to main advantages. First, it permits to model possible abrupt break in the evolution of parameters that might occur during the estimation period. Second, it permits also to model gradual changes in the relationship between variables as a result of an adaptative learning behavior of individuals. Therefore, unlike multivariate models used in the literature that model either structural break or persistence, the TVP-VAR encompasses these two important features of the relationship between variables that might occur at different periods in our sample.

Moreover, innovations in the reduced-form model are assumed to be jointly distributed

$$\begin{pmatrix} \upsilon_t \\ \omega_t \\ \zeta_t \\ \eta_t \end{pmatrix} \rightsquigarrow \mathcal{N}(\mathbf{0}, V) \text{ with } V = \begin{pmatrix} \mathbf{I}_n & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & Q & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & S & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & W \end{pmatrix}$$

where the matrix S is block diagonal. That is, we assume that blocks, corresponding to contemporaneous coefficients in each equation, are mutually independent. Each block of S corresponds to the variance-covariance matrix of contemporaneous coefficients of each equation.

3. Empirical results

The time-varying VAR parameter approach allows us to study the evolution of the crude oil price elasticity with respect to the effective exchange rate of the dollar, the HWWI index, the Gold prices and the dry cargo index.

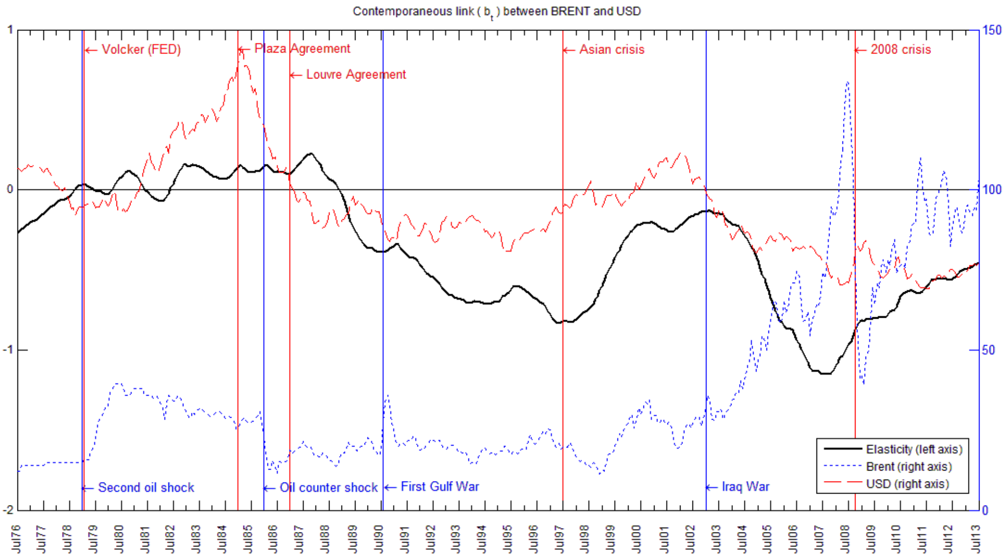
3.1 Elasticities

3.1.1 Brent and Effective Exchange rate of the dollar

We report the evolution of the USD elasticity of the oil price in figure 1[7]. Except during the 1979-1989 period where the elasticity is positive (between 0.0 and 0.2), the relation between the effective exchange rate of the dollar and the oil price is negative. It highlights the fact that a depreciation of the effective exchange rate of the dollar leads to an oil price increase. From 1989 to 2013 we then observe a succession of elasticity's cycles: from 1989 to 1997 (from 0.0 to -0.8), from 1997 to mid-2003 (from -0.8 to -0.2), from mid-2003 to June 2008 (from -0.2 to -1.2) and from 2008 to 2013 (from -1.2 to -0.45).

[7] Figures including confidence intervals are reported in Appendix C (Figure 6).

Figure 1: USD Elasticity of Brent



Source: Authors calculation

The first period (1979-1989) is characterized by an increase of the crude oil prices in the wake of the second world oil shock. Moreover in August 1979 in the US, Paul Volcker became the chairman of the Federal Reserve Bank and decided to raise the federal fund rate from around 11% in 1979 to a peak at 20% in 1981. This policy led to an increase of about 45% of the effective exchange rate of the dollar between 1979 and 1985. Thereafter the Plaza agreement in 1985 between France, Japan, the United Kingdom, the US, and West Germany has led to a sharp depreciation of the effective exchange rate of the dollar between 1985 and 1989. At the same time in the oil market the OPEC and notably Saudi-Arabia, which reduced its oil production from 9.9 million barrels per day (mb/d) to 3.3 mb/d, started to defend the level of the oil prices. Despite this strategy, the oil prices collapsed in 1986 to less than 10 USD per barrel.

During the second period (1989-2013) the relation between the effective exchange rate of the dollar and the oil prices is negative with an elasticity range from 0.0 to -1.2. These two decades are characterized by two key trends. Except during the Gulf War (1991) and the Asian crisis (1997-1999) the oil market was relatively stable during the 1990s. However the effective exchange rate of the dollar was quite volatile with a strong appreciation process of the USD between 1996 and 2002. Two important processes can explain the evolution of the elasticity during the 2000s. In 2001, after ten year of economic expansion, the American GDP started to contract. The Federal Reserve Bank decided to launch an aggressive easing monetary policy with a sharp decline of the federal fund rate (from 6.5% in January 2001 to 1% in June 2003). This movement helps the effective exchange rate of the dollar to heavily depreciate. During the same time, fuelled by the economic development of the BRICs economies and more especially China, the world entered a new era with a sharp increase of oil prices (from 40 USD per barrel in 2004 to 70 USD in 2007 and the peak of around 145 USD in July 2008). It explains the elasticity path from 2001 to 2008 (-0.2 to -1.2).

The relationship between the two variables tends to reinforce during the depreciation periods, whereas it weakens during the episodes of appreciation. This illustrates an "asymmetric response" between the oil price and the exchange rate depending on the global economic context. A possible explanation can be found in studying the oil producers behavior. Indeed, a depreciation of the exchange rate (and then a decrease in the value of the oil production) should be followed by an increase of the crude oil price, other things being equal, in order that the producers to maintain their oil revenues. Some studies (Alhajji & Huettner, 2000 among others) pointed out this kind of policy as a target revenue strategy. But we should add that there is a strong assumption behind this strategy. Indeed it assumes that the producers have the ability to be the price makers in the market whatever the market conditions. This hypothesis remains uncertain from 1973 to 2009 (Brémond et al., 2012). At the opposite, an appreciation of the Dollar does not trigger any decrease of the crude oil price. It is worth noting that the relationship appears to be weaker during these periods.

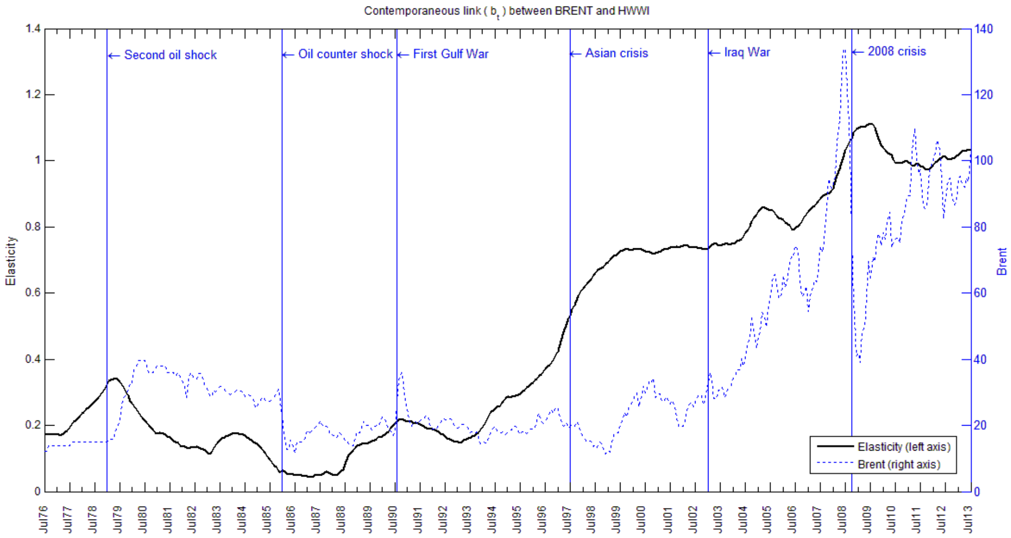
3.1.2 Elasticity between HWWI and Brent

Turning to the HWWI raw materials index, figure 2 shows that the elasticity with the Brent is positive and is reinforced in our sample (from 0.2 to 1.1). It illustrates the common trend observed from 2001 to 2008 in the non energy commodities and in the energy markets.

Indeed although the timing and the magnitude have been different in the various commodities markets (energy, non-ferrous metals, agricultural raw materials and beverages), the price increase that began in late 2001 in the non-ferrous metals had spread into all commodities markets by 2004-2005 in the context of steady world economic growth. This result highlights the possible existence of spillover effect between energy and industrial raw material prices.

The financialisation process of the commodities markets observed since the beginning of 2000 in the wake of the Commodity Future Modernisation Act (CFMA) could explain the reinforcement of the elasticity since the turn of the century. The new financial tools such as the Exchange Traded Fund (ETF) offered by the financial sector could help to understand this result. Masters (2008) in a Testimony and in different reports for the United States Senate launched the controversial debate about the role of Index commodities funds as drivers of speculation in all the commodities markets. The new hedging strategies and the speculative trading (Hache and Lantz, 2013) that can occur between different market places (New York and London for example) with different commodities (energy, non-ferrous metals and beverages) could also explain this result.

Figure 2: HWWI Elasticity of Brent

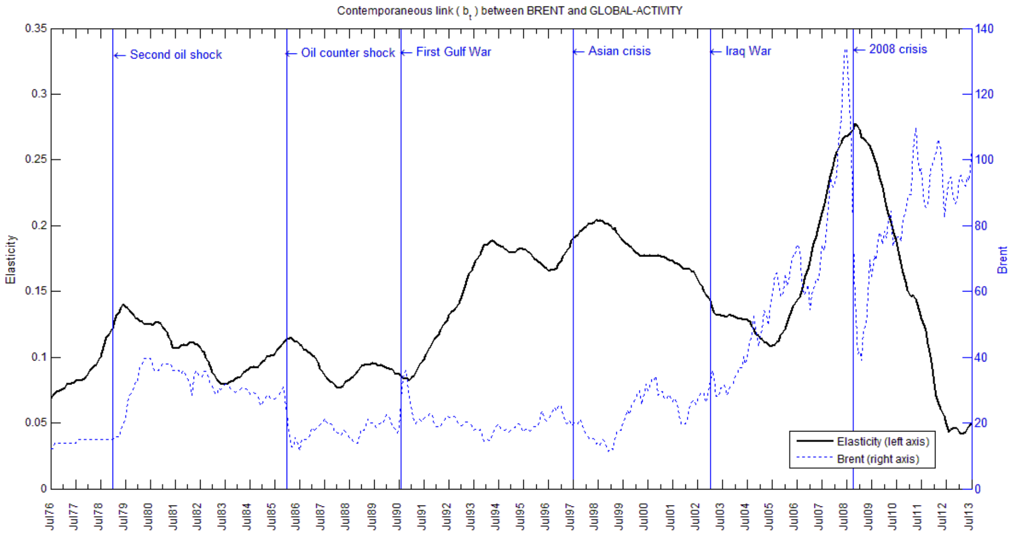


Source: Authors calculation

1.1.1 Elasticity between Global Activity and Brent

As shown in figure 3, the relationship between the global activity and the crude oil price is positive during all our sample period and reinforced between 1991 and 1999. This illustrate the prominent role of demand as a driver of oil price as argued by Kilian (2009) and Kilian et al. (2009). The steady increase in the elasticity until the 2008 world trade collapse (from 0.07 to 0.27) illustrate the short run vertical oil supply curve and inelastic oil demand stated in the literature. Namely, Baumeister and Peersman (2013) argue that these findings are mainly explained by the efficiency gains observed since the second oil shock and by changes in the total composition of oil demand. The increasing outsoursing of industrialized production towards emerging countries where oil prices are subsidized by governments renders oil demand less responsive to oil prices. This is reinforced by the fact that industrialized countries are now oriented to services and efficiency gains, namely for transport sector, lead oil demand less reponsive to rise in oil price.

Figure 3: Global Activity elasticity of Brent



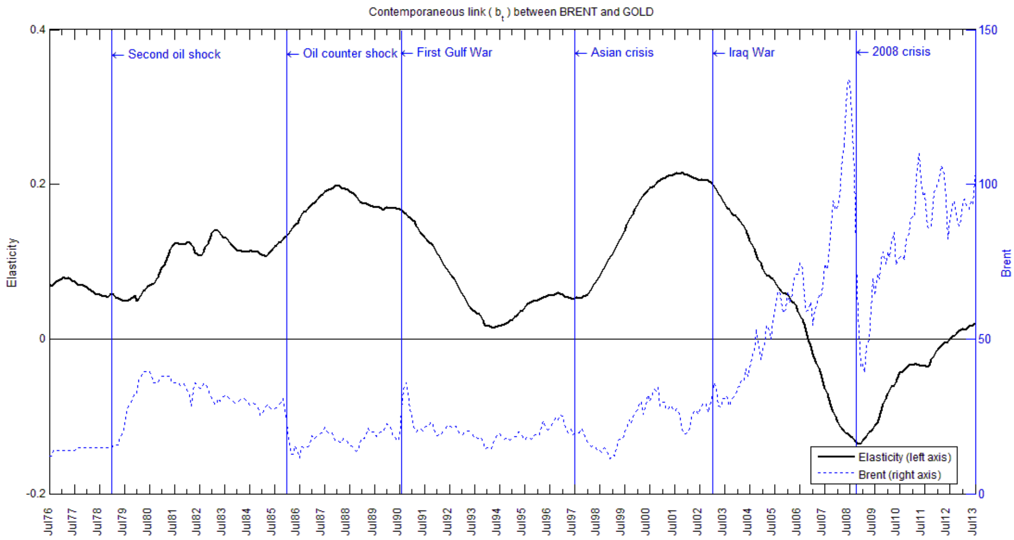
Source: Authors calculation

1.1.1 Elasticity between Gold and Brent

As shown in figure 4, the relationship between gold price and the crude oil price is quite instable. The elasticity which was positive from 1976 to 2007 became negative afterward. The shape of the gold elasticity of brent follows the shape of the effective exchange rate of the dollar with a sharp appreciation between 1979 and 1985 and between 1994 and 2002, and a depreciation from 1985 to 1994 and from 2003 to 2008. It then highlights the relationship between these 3 variables : the crude oil price, the gold price and the effective exchange rate of the dollar.

The 2002-2013 period is very interesting. In the wake of the financial crisis of 2007-2008, the crude oil price collapsed from 145 USD to less than 40 USD at the end of 2008. During the same time the Gold price registered a sharp increase. Two elements can explain this fact. On the one hand we can consider that the traditionnal safe haven asset theory reinforced during this post-crisis period and helped to boost the gold prices in the market. On the other hand it could be explained by the growing monetization of the gold market.

Figure 4: Gold Elasticity of Brent



Source: Authors calculation

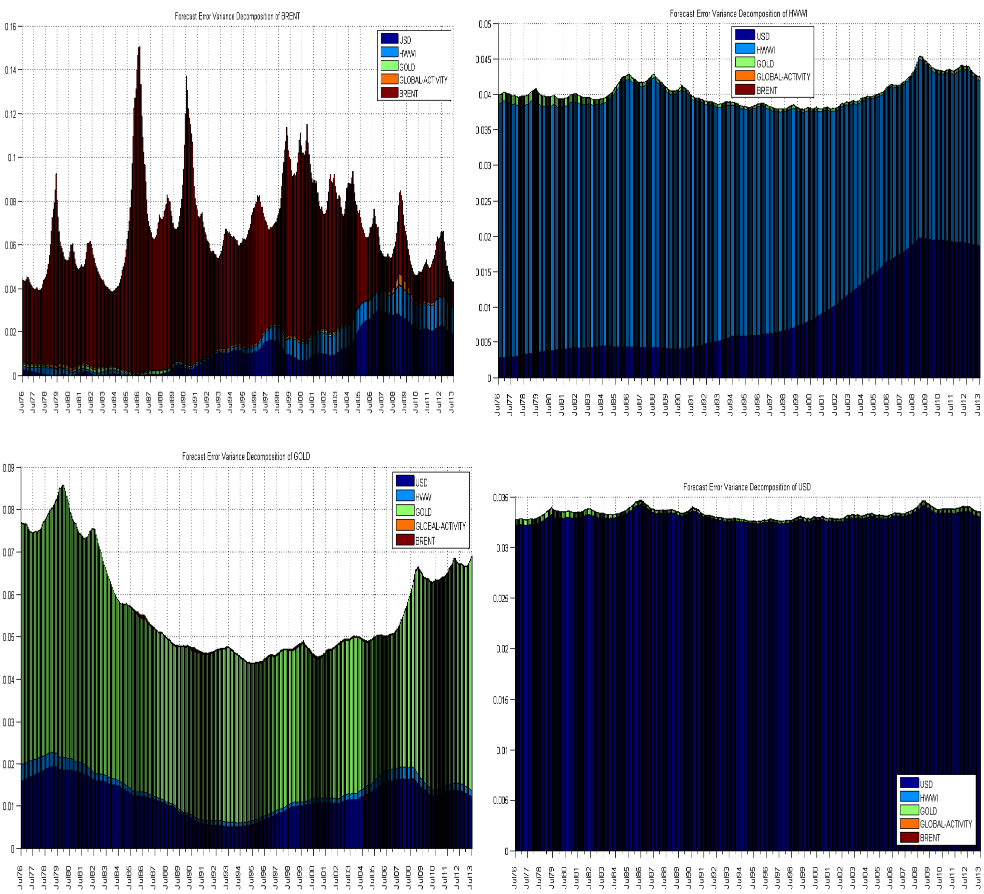
1.2 Forecast Error Variance Decomposition (FEDV)

The Forecast Error Variance Decomposition (henceforth FEDV) in figure 5 measures the contribution of different variables in the model to the volatility of the variable of interest. They are calculated for the whole sample of estimation. It should contribute to a more comprehensive analysis of our subject with regards to time-changing economic environment pattern and monetary policy during the estimation period.

Regarding the Forecast Error Variance Decomposition of Brent, several conclusions emerge. First, oil price volatility is time-varying. Mainly, there is a sustained increase of oil price volatility from 1976 to 2001 as evidenced in the literature with a peak on 1986 and 1990. Thereafter, the volatility of the Brent decreases. It coincides with the rise in global activity fuelled by the economic development of the BRICs economies and more especially China that leads to a sustained rise, hence less volatile, oil price. Second, with the exception of some abnormal price movements occurring in the market (1979, 1986, 1991 and 2008), Brent variance is less and less self-explained. Third, USD and HWWI variance impacts are more and more important, especially after the beginning of the 21st century.
The Gold FEDV is globally explained by its self-variance (and so fundamentals) and also by USD variance, as this commodity is priced in USD.

The HWWI is mainly explained by two variances. Thus, while the share of USD variance explanation ramped up since the end of 1990s (reaching half of the explanation), the explanation through the HWWI variance decreases from around 90% to 50%. This results is interesting, considering the fact the majority of commodities involved in HWWI composition are priced in USD. Regarding the FEDV of USD, we can note that USD variance is remarkably self-explained and flat since 1976. This might be explained by the fact that the direction of bilateral USD exchange rate changes after an oil price changes depends on the country considered. Lizardo and Mollick (2010) argue that currencies of oil exporting countries appreciate relative to the US dollar while those of oil importing countries depreciate relative to the US Dollar following a rise in oil price. Thus, the final effect of oil price changes on the effective exchange rate of US Dollar considered in this study might be dampened.

Figure 5: Forecast Error Variance Decomposition (FEDV)



Source: Authors calculation

2. Conclusion

Using Bayesian time-varying VAR parameters methodology, this paper contributes to the literature related to the link between exchange rate and oil price. We conclude that both the elasticity of crude oil prices with respect to a set of variables and the forecast error variance decomposition (FEDV) of these variables vary across time. Moreover we demonstrate that a depreciation of the effective exchange rate leads to an oil price increase though the magnitude of changes vary across time depending on the economic context that prevails. We also highlight the increasing role of the other commodities markets in the oil price dynamics. The HWWI index seems to become a very important explaining factor for understanding the oil price behavior. We thus could deepen the subject in focusing on the specific relationship between the oil market and the other commodities markets. These results are confirmed by the FEDV conclusions, reflecting that the HWWI and the effective exchange rate of the dollar variances contribute to the explanation of the Brent price volatility.

Taking all these results into account leads us to conclude that the previous studies based only on the US economy and the oil price reflected a small share of the economic reality. Thus, we have to improve our knowledge of new factors such as the exchange rate and the commodities, and new actors such as China in order to understand the oil price setting and its behavior in the world market. Moreover, monetary policies from ECB or Fed (through the Quantitative Easing and its progressive tapering) may impact emerging countries (such as China, Turkey, Indonesia, Brazil or South Africa) which are more and more the new players of commodity market. Taking into account these impacts is also necessary.

References

Akram, Q.F. (2009), "Commodity prices, interest rates and the dollar", *Energy Economics*, 31, 838-851.

Alhajji, A.F. and Huettner, D. (2000), "OPEC and other Commodity cartels: a comparison", *Energy Policy*, 28, 1151-1164.

Amano, R.A. and van Norden, S. (1998a), "Oil prices and the rise and fall of the U.S. real exchange rate", *Journal of International Money and Finance*, 17(2), 299-316.

Amano, R.A. and van Norden, S. (1998b), "Exchange rates and Oil Prices", *Review of International Economics*, 6(4), 683-694.

Baumeister, C. and Peersman, G. (2013), "Time-varying effects of oil supply shocks on the US economy", *American Economic Journal: Macroeconomics*, 5(4), 48-64.

Beckmann, J. and Czudaj, R. (2013), "Is there a homogeneous causality pattern between oil prices and currencies of oil importers and exporters?", *Energy Economics*, 40, 665-678.

Bénassy-Quéré, A., Mignon, V. and Penot, A. (2007), "China and the relationship between the oil price and the dollar", *Energy Policy*, 35, 5795-5805.

Brémond, V., Hache, E. and Mignon, V. (2012), "Does OPEC still exist (as a cartel)? An empirical investigation", *Energy Economics,* 34, 125-131.

Benhmad, F. (2012), "Modeling nonlinear Granger causality between the oil price and U.S. dollar: A wavelet based approach", *Economic Modelling*, 29, 1505-1514.

Carter, C. K. and Kohn, R. (1994), "On Gibbs sampling for state space models", *Biometrika*, 81(3), 541-553.

Chen, S-S. and Chen, H-C. (2007), "Oil prices and real exchange rates", *Energy Economics*, 29, 390-404.

Cogley, T. and Sargent, T. J. (2005), "Drift and volatilities: Monetary policies and outcomes in the post WWII U.S.", *Review of Economic Dynamics,* 8(2), 262-302.

Dickey, D.A. and Fuller, W.A. (1981), "Likehood Ratio Statistics for Autoregressive Time Series With a Unit Root", *Econometrica*, 49, 1057-1072.

Engle, R.F. and Granger, C.W.J. (1987), "Cointegration and Error Correction: Representation, Estimation and Testing", *Econometrica*, 55, 251-276.

Geweke, J. (1992), "Evaluating the accuracy of sampling-based approaches to the calculation of posterior moments", *Bayesian Statistics*, 4, 641-649.

Golub, S. S. (1983), "Oil Prices and Exchange Rates", *The Economic Journal*, 93, 576-593.

Hache, E., and Lantz, F. (2013), "Speculative trading and oil price dynamic: A study of the WTI market", *Energy Economics*, 36, 334-340.

Johansen, S. and Juselius, K. (1990), "The full information maximum likelihood procedure for inference on cointegration", *Oxford Bulletin of Economics and Statistics*, 52: 169-210.

Kilian, L. (2009), "Not all oil price shocks are alike: disentangling demand and supply shocks in the crude oil market", *American Economic Review*, 99(3), 1053-69.

Kilian, L., Rebucci, A. and Spatafora, N. (2009). "Oil shocks and external balances." *Journal of International Economics*, 77(2), 181-194.

Kim, S., Shepard, N. and Chib, S. (1998), "Stochastic volatility: Likehood inference and comparison with ARCH models", *Review of Economic Studies*, 65(3), 361-93.

Krichene, N. (2007), "An Oil and Gas Model", *IMF Working Paper*, WP/07/135.

Krugman, P. (1980), "Oil and the Dollar", *NBER Working Paper*, No. 554.

Krugman, P. (1983), "Oil shocks and exchange rate dynamics", *Exchange rates and international macroeconomics*, edited by J.A. Frankel. Chicago: University of Chicago Press

Lizardo, R. A. and Mollick, A. V. (2010), "Oil price fluctuations and U.S. dollar exchange rates", *Energy Economics*, 32, 399-408.

Masters, M.W. (2008), "Testimony before the Committee on Homeland Security and Governmental Affairs", United States Senate, May 20.

Percebois, J. (2009), "Prix internationaux du pétrole, du gaz naturel, de l'uranium et du charbon : la théorie économique nous aide-t-elle à comprendre les évolutions ?", *Cahiers de Recherche du CREDEN*, N°09.02.81.

Phillips, P.C.B. and Perron, P. (1988), "Testing for a Unit Root in a Time Series Regression", *Biometrika*, 75, 335-346.

Primiceri, G. E. (2005), "Time-varying structural vector autoregressions and monetary policy", *The review of Economic Studies*, 72(3), 821-852.

Raferty, A.E., and Lewis, S. M. (1995), "The number of iterations, convergence diagnostics and generic Metropolis algorithms. In Practical Markov Chain Monte Carlo", W.R. Gilks, D.J. Spielgelhater and S. Richardson, chapman and hall, London.

Reboredo, J.C., Rivera-Castro, M.A. and Zebende, G.F. (2014), "Oil and US dollar exchange rate dependence: A detrended cross-correlation approach", *Energy Economics*, 42, 132-139.

Sadorsky, P. (2000), "The empirical relationship between energy futures and exchange rates." *Energy Economics*, 22, 253-266.

Zivot, E. and Andrews, D. (1992), "Further evidence of great crash, the oil price shock and unit root hypothesis", *Journal of Business and Economic Statistics*, 10, 251-270.

Appendices:

A. HWWI Commodity Price Index Methodology

The HWWI index is a monthly commodity price index developed by the Hamburg Institute of International Economics (HWWI) in Germany. The index measures the changes observed in the commodity prices and is considered as an indicator of developments in the cost of imported raw materials. The HWWI index is split in different sub-indexes: HWWI index TOTAL, HWWI index excluding energy, HWWI energy raw materials, HWWI industrial raw materials, HWWI Food Total. According to AIECE Report (2013), the weights for individual commodities are based on their share in total commodities imports of the OECD countries, excluding intra-EU trade.

The weights of the different commodities and commodity groups in the HWWI index we used in our study are the following:

per cent share in:	total	excl. energy		total	excl. energy
HWWI index, total	100		**Industrial raw materials**	15,4	73,8
Total excl. energy	20,8	100	Agricultural raw materials	4,3	20,6
			- Cotton	0,1	0,6
Food total	5,5	26,2	- Wool	0,1	0,4
			- Hides	0,1	0,7
Cereals	1,4	6,9	- Natural rubber	0,8	3,9
- Barley	0,0	0,2	- Wood	1,8	8,9
- Maize	0,7	3,4	- Woodpulp	1,3	6,1
- Wheat	0,5	2,3			
- Rice	0,2	0,9	Non-ferrous metals	7,9	37,9
			- Aluminium	3,7	17,6
Oilseeds, vegetable oils	1,9	9,1	- Copper	2,5	12,2
- Soybeans	0,7	3,5	- Lead	0,2	0,8
- Soybean meal	0,8	3,7	- Nickel	0,9	4,4
- Soybean oil	0,1	0,2	- Tin	0,2	0,9
- Coconut oil	0,1	0,4	- Zinc	0,4	2,0
- Palm oil	0,2	0,8			
- Sunflower oil	0,1	0,5	Iron ore, steel scrap	3,2	15,3
			- Iron ore	2,2	10,8
Tropical beverages, sugar	2,1	10,3	- Steel scrap	0,9	4,5
- Coffee	1,2	5,6			
- Cocoa	0,5	2,2	**Energy raw materials**	79,2	
- Tea	0,2	0,7	- Coal	4,5	
- Sugar	0,4	1,8	- Crude oil	74,6	

[1] Based on world imports of OECD countries minus Intra-EU trade, 2005-2007

B. Unit Root Tests

Before implementing the estimation, we proceed to three different unit root tests to determine the order of integration of each series: Augmented Dickey-Fuller (1981) (ADF), Philips and Perron (1988) (PP) and the Zivot and Andrews (1992) tests. Relying on the ZA test allow us to account for the presence of structural breaks and then consolidate our results. For the ADF and PP tests, the null hypothesis is the non stationarity. For the Zivot and Andrews procedure, the null hypothesis is the presence of a unit root without any exogenous structural break, while the alternative hypothesis is characterized by the stationarity with a break date endogenously determined. The structural breaks for the two elements are tested on the trend and on the constant term. As shown in Table 1, our series are integrated of order 1. We thus first-differentiate our variables in order to control for non-stationarity in our estimation.

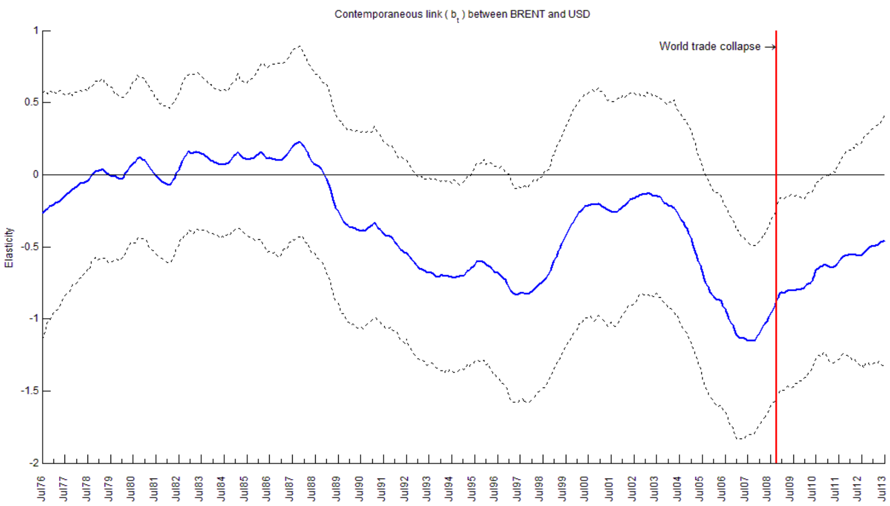
Table 1. Results of ADF, Philips-Perron & Zivot and Andrews tests

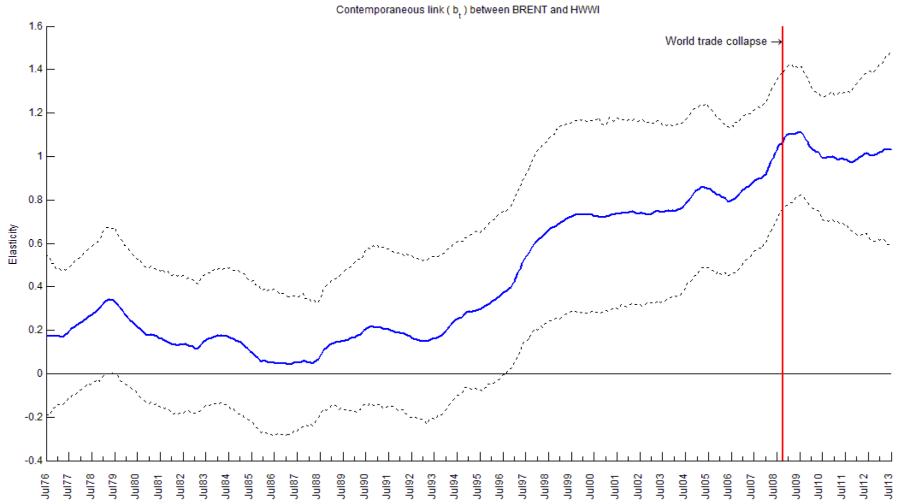
1976m7-2013m7	**Brent**	**USD**	**Gold**	**HWWI**
ADF	I(1)	I(1)	I(1)	I(1)
PP	I(1)	I(1)	I(1)	I(1)
Z&A	I(1)	I(1)	I(1)	I(1)

I(0) (resp. I(1)): series are integrated of order 0 (resp. 1).

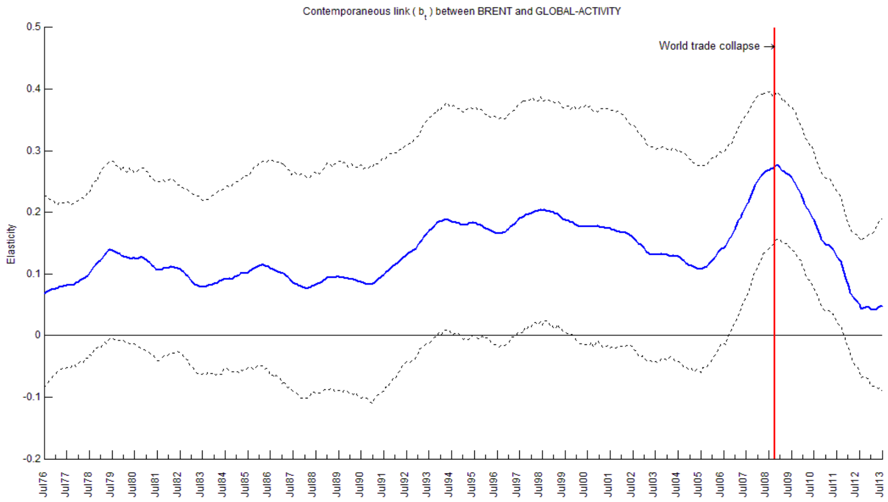
C. Other Figures

Figure 6: Elasticities with confidence intervals

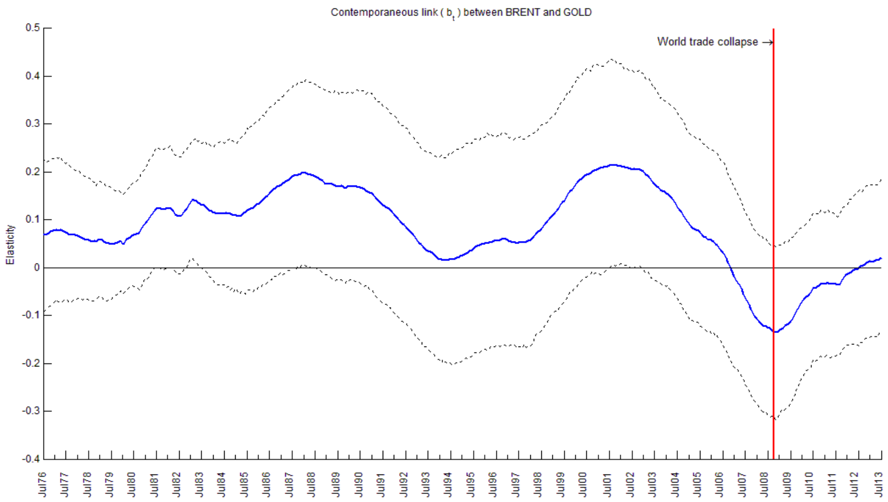




Contemporaneous link (b_t) between BRENT and HWWI
World trade collapse →
Elasticity

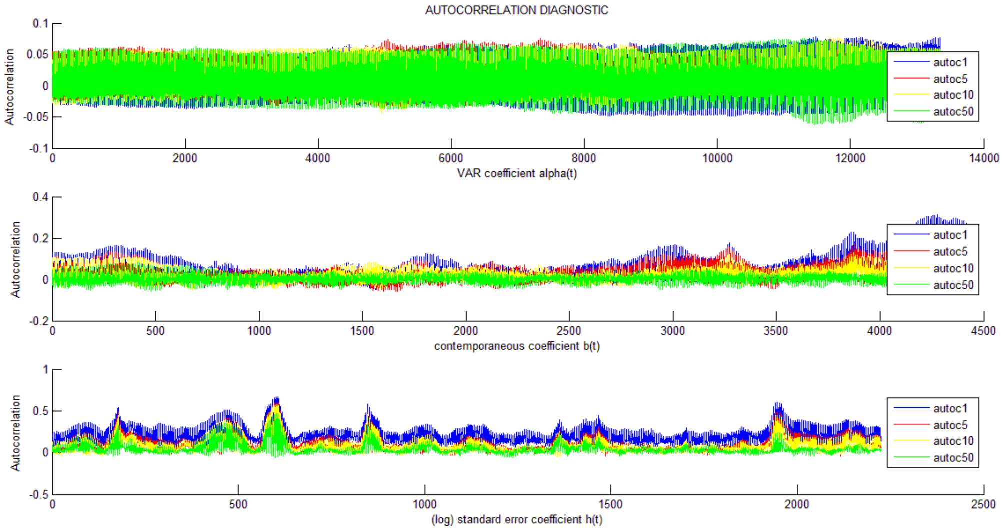


Contemporaneous link (b_t) between BRENT and GLOBAL-ACTIVITY
World trade collapse →
Elasticity



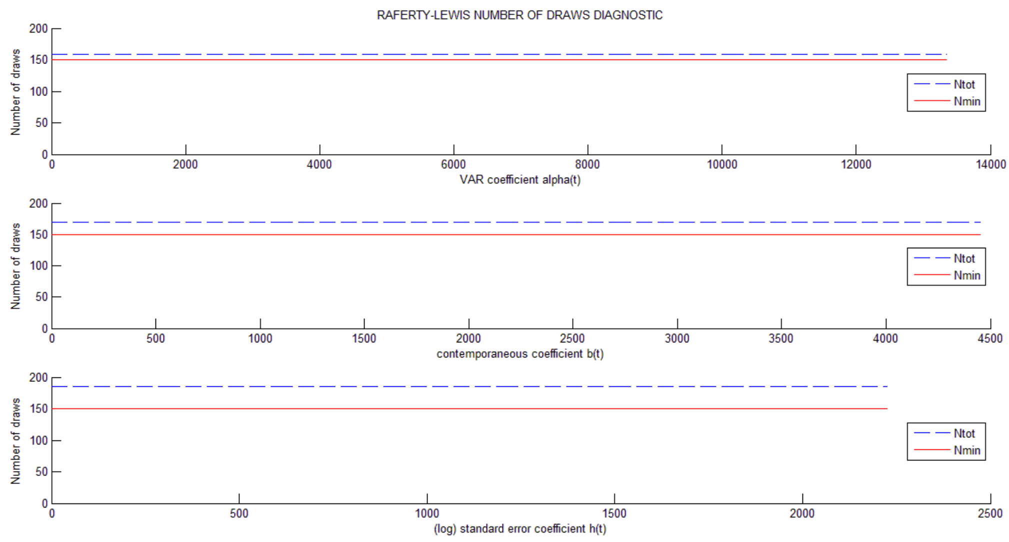
Contemporaneous link (b_t) between BRENT and GOLD
World trade collapse →
Elasticity

Figure 7: Autocorrelation diagnostic



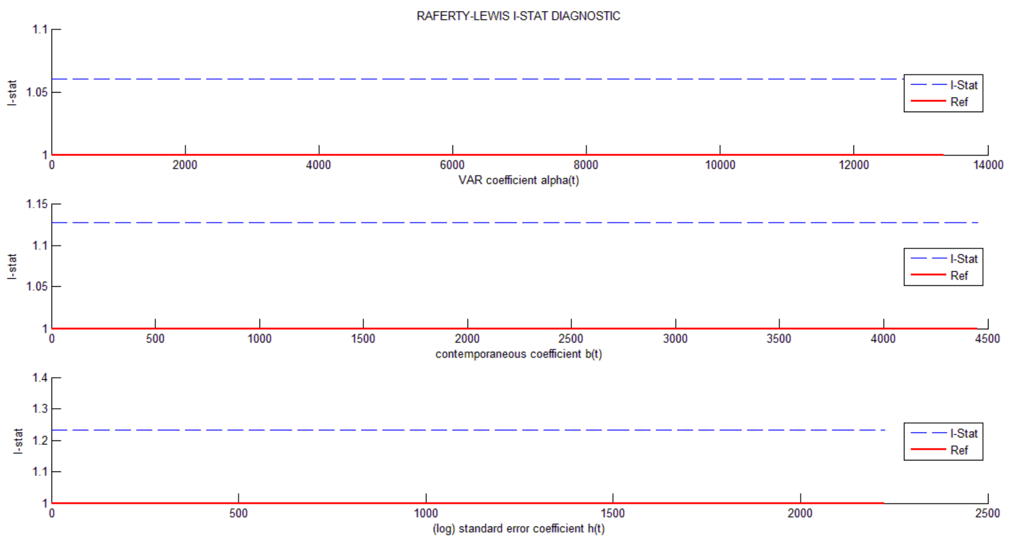
Source: Authors calculation

Figure 8: Raferty-Lewis "Number of draws" diagnostic



Source: Authors calculation

Figure 9: Raferty-Lewis "I-STAT" diagnostic



Source: Authors calculation

D. Time-varying VAR model

D.1 State-space representation

In order to estimate the parameters of interest, the reduced form VAR model (2) can be rewritten as:

$$\begin{aligned} Y_t &= \begin{pmatrix} c_t & A_{1,t} & \cdots & A_{p,t} \end{pmatrix} \begin{pmatrix} 1 & Y'_{t-1} & \cdots & Y'_{t-p} \end{pmatrix}' + \epsilon_t \\ &= A_t Z_{t-1} + \epsilon_t \end{aligned}$$

Vectorization of the last equation yields

$$Y_t = \left(Z'_{t-1} \otimes I_n\right) \alpha_t + \epsilon_t \qquad (4)$$

where α_t is a vector column that contains stacked columns of matrix A_t and $\otimes$ denotes the Kronecker products.

D.1.1 Reduced form VAR

State space representation of the reduced form VAR representation (2) can be obtained using (4) and the time paths of lag coefficients α_t (5). That is,

$$\begin{cases} \alpha_t = \alpha_{t-1} + \omega_t \\ Y_t = \left(Z'_{t-1} \otimes I_n\right) \alpha_t + B_t^{-1} \Sigma_t \upsilon_t \end{cases} \qquad (6)$$

where the residuals of state and measurement equations are assumed to be normally distributed. That is,

$$\omega_t \rightsquigarrow \mathcal{N}(0, Q) \;\; \upsilon_t \rightsquigarrow \mathcal{N}(0, \mathbf{I}_n)$$

Knowing that innovations $\{w_t, v_t\}_{t=1}^{T}$ are multivariate Gaussian, if the initial value of VAR parameters α_0 is also Gaussian, the entire sequences of $\{\alpha_t\}_{t=1}^{T}$ can be generated *via* forward and backward recursion of Kalman filter conditional on[8] Y_t, B_t, Σ_t and Q. Therefore, as shown in Cogley and Sargent (2005), joint posterior density for VAR parameters is a product of independent normal distribution. That is,

$$p\left(\alpha_T | Y_T, B_T, \Sigma_T, Q\right) = f\left(\alpha_T | Y_T, B_T, \Sigma_T, Q\right) \prod_{t=1}^{T-1} f\left(\alpha_t | \alpha_{t+1}, Y_t, B_t, \Sigma_t, Q\right) \qquad (7)$$

where both posterior density $p(\cdot)$ and density functions $f(\cdot)$ are linear Gaussian with means and variances given by

[8] Or, in other words, assuming that the entire sequence of contemporaneous coefficients and standard errors $\{B_t, \Sigma_t\}_{t=1}^{T}$ are known or given, as well as the variance-covariance matrix Q.

$$\begin{aligned}\alpha_{t|t+1} &= E\left(\alpha_t|\alpha_{t+1}, Y_t, B_t, \Sigma_t, Q\right)\\ P_{t|t+1} &= Var\left(\alpha_t|\alpha_{t+1}, Y_t, B_t, \Sigma_t, Q\right)\end{aligned}$$

D.1.2 Contemporaneous coefficients

Let us define

$$\hat{Y}_t = Y_t - \left(Z'_{t-1} \otimes I_n\right)\alpha_t = B_t^{-1}\Sigma_t \upsilon_t$$

where $\hat{Y}_T$ will be observable when α_t is known or given. Since B_t is lower triangular matrix with ones along the diagonal and Σ_t is a diagonal matrix, the equality $B_t\hat{Y}_t = \Sigma_t \upsilon_t$ can be written by equation as

$$\begin{aligned}\hat{Y}_{2t} &= -\hat{Y}_{1t}b_{21,t} + \sigma_{2,t}\upsilon_{2t}\\ \hat{Y}_{3t} &= -\left(\hat{Y}_{1t}\ \hat{Y}_{2t}\right)\begin{pmatrix} b_{31,t}\\ b_{32,t}\end{pmatrix} + \sigma_{3,t}\upsilon_{3t}\\ \vdots &= \vdots\\ \hat{Y}_{nt} &= -\left(\hat{Y}_{1t}\ \hat{Y}_{2t}\ \cdots\ \hat{Y}_{n-1t}\right)\begin{pmatrix} b_{n1,t}\\ b_{n2,t}\\ \vdots\\ b_{nn-1,t}\end{pmatrix} + \sigma_{n,t}\upsilon_{nt}\end{aligned}$$

Moreover, under the block diagonality assumption of S and conditional on Y_t, α_t, Σ_t, S and I_n, each block of the vector of contemporaneous coefficients b_t is computed *via* forward and backward recursion of Kalman filter applied to state space representation of the corresponding equation. That is, for $i = 2, \dots, n$

$$\left\{\begin{array}{l} b_{[i]t} = b_{[i]t-1} + \zeta_{[i]t}\\ \hat{Y}_{it} = -\hat{Y}_{[1,\dots,i-1]t}b_{[i]t} + \sigma_{i,t}\upsilon_{it}\end{array}\right. \tag{8}$$

where $b_{[i]t}$ is the block of the vector b_t corresponding to the i^{th} equation, $\zeta_{[i]t}$ is the i^{th} block of the vector of state errors corresponding to $b_{[i]t}$ with

$$\zeta_{[i]t} \rightsquigarrow \mathcal{N}(\mathbf{0}, S_{[i]})$$

where $S_{[i]}$ is the i^{th} block of the matrix S, and $\hat{Y}_{[1,\dots,i-1]t}$ denotes a row vector $\hat{Y}_{1t}\ \hat{Y}_{2t} \cdots \hat{Y}_{i-1t}$. Like VAR parameters in the previous subsection, joint posterior density for contemporaneous coefficients is given by

$$p\left(b_{[i]T}|\hat{Y}_{[1,...,i]T},\sigma_{i,T},S_{[i]}\right) = f\left(b_{[i]T}|\hat{Y}_{[1,...,i]T},\sigma_{i,T},S_{[i]}\right) \prod_{t=1}^{T-1} f\left(b_{[i]t}|b_{[i]t+1},\hat{Y}_{[1,...,i]T},\sigma_{i,T},S_{[i]}\right) \quad (9)$$

where posterior density $p(\cdot)$ and density functions $f(\cdot)$ are linear Gaussian with means and variances given by

$$\begin{aligned} b_{[i]t|t+1} &= E\left(b_{[i]t}|b_{[i]t+1},\hat{Y}_{[1,...,i]T},\sigma_{i,T},S_{[i]}\right) \\ \Lambda_{[i]t|t+1} &= Var\left(b_{[i]t}|b_{[i]t+1},\hat{Y}_{[1,...,i]T},\sigma_{i,T},S_{[i]}\right) \end{aligned}$$

D.1.3 Standard error coefficients

Let us define

$$Y_t^* = B_t\hat{Y}_t = \Sigma_t v_t \quad (10)$$

It is worth noting that when B_t is known (or conditional on B_t), Y_t^* is observable. Unlike measurement equation above, this is a non-linear system. However, it can be easily transformed into a linear one by squaring and taking natural logarithm of each equation in (10). That is, for the i^{th} equation,

$$\begin{aligned} Y_{it}^* &= \sigma_{i,t}v_{it} \\ (Y_{it}^*)^2 &= (\sigma_{i,t}v_{it})^2 \\ \ln\left((Y_{it}^*)^2\right) &= 2\ln(\sigma_{i,t}) + \ln\left(v_{it}^2\right) \end{aligned}$$

Notice that the element $(Y_{it}^*)^2$ might be very small. Thus, in order to have more robust estimation, it is necessary to add $(Y_{it}^*)^2$ with a constant correction $\bar{c} = 0.001$. That is,

$$\begin{aligned} \ln\left((Y_{it}^*)^2 + \bar{c}\right) &= 2\ln(\sigma_{i,t}) + \ln\left(v_{it}^2\right) \\ Y_{it}^{**} &= 2h_{it} + u_{it} \end{aligned}$$

State space representation of the vector of standard-error coefficients h_t is therefore given by

$$\begin{cases} h_t = h_{t-1} + \eta_t \\ Y_t^{**} = 2h_t + u_t \end{cases} \quad (11)$$

where

$$\eta_t \rightsquigarrow \mathcal{N}(\mathbf{0}, W).$$

It is worth noting that measurement errors u_t no longer follow a normal distribution. Instead, they are distributed as $\ln(\chi^2(1))$. However, as in Kim et al. (1998), $\ln(\chi^2(1))$ distribution can be approximated, according to a $(n \times T)$ matrix of indicator variables $D_t = (d_1\, d_2 \cdots d_T)$, by a mixture of 7 normal distributions with probabilities $q_j = Pr(w = j)$ for $j = 1, \ldots, 7$, means $E(w) = m_j - 1.2704$, and variances $Var(w) = v_j^2$. The parameters of the relevant distribution are selected from the following table

Mixture Distribution

ω	q_j	m_j	ν_j^2
1	0.00730	-10.12999	5.7956
2	0.10556	-3.97281	2.61369
3	0.00002	-8.56686	5.17950
4	0.04395	2.77786	0.16735
5	0.34001	0.61942	0.64009
6	0.24566	1.79518	0.34023
7	0.25750	-1.08819	1.26261

Source: Kim et al. (1998)

Conditional on Y_t^{**} and W, joint posterior density of standard error vector of parameters is given by

$$p\left(h_T|Y_T^{**}, W\right) = f\left(h_T|Y_T^{**}, W\right) \prod_{t=1}^{T-1} f\left(h_t|h_{t+1}, Y_t^{**}, W\right) \qquad (12)$$

where posterior density $p(\cdot)$ and density functions $f(\cdot)$ are now linear Gaussian with means and variances given by

$$\begin{aligned} h_{t|t+1} &= E\left(h_t|h_{t+1}, Y_t^{**}, W\right) \\ H_{t|t+1} &= Var\left(h_t|h_{t+1}, Y_t^{**}, W\right) \end{aligned}$$

It is worth noting that given Y_t^{**} and h_t, a new selection matrix D_t can be generated by sampling from

$$P\left(d_{it} = k|Y_{it}^{**}, h_{it}\right) \propto q_j f_N\left(Y_{it}^{**}|2h_{it} + m_j - 1.2704, \nu_j^2\right)$$

for $j = 1, \ldots, 7$ and $i = 1, \ldots, n$.

D.2 Kalman filter and Gibbs sampling

Consider the linear Gaussian state space model

$$\begin{cases} \xi_t = \mathbf{T}\xi_{t-1} + \mathbf{c} + \mathbf{R}\eta_t \\ Y_t = \mathbf{Z}_t\xi_t + \mathbf{d} + \varepsilon_t \end{cases}$$

where ξ_t is the unobservable state vector, Y_t is the vector of observations, and η_t and ε_t are the vectors of serially uncorrelated disturbances with mean 0 and covariance matrices Q and H_t. That is,

$$\begin{bmatrix} \eta_t \\ \varepsilon_t \end{bmatrix} \rightsquigarrow \mathcal{N}\left(\begin{bmatrix} \mathbf{0} \\ \mathbf{0} \end{bmatrix}, \begin{bmatrix} \mathbf{Q} & \mathbf{0} \\ \mathbf{0} & \mathbf{H}_t \end{bmatrix}\right)$$

D.2.1 Forward recursion of Kalman filter

Define

$$\begin{aligned} \xi_{t|t-1} &= E\left\{\xi_t | Y_{t-1}, \mathbf{Z}_{t-1}, \mathbf{H}_{t-1}, \mathbf{Q}\right\} \\ P_{t|t-1} &= E\left\{\left(\xi_t - \xi_{t|t-1}\right)\left(\xi_t - \xi_{t|t-1}\right)'\right\} \end{aligned}$$

where $\xi_{t|t-1}$ denotes the linear projection of ξ_t on Y_{t-1}, Z_{t-1}, H_{t-1}, Q and a constant (the forecast of ξ_t), and $P_{t|t-1}$ the mean squared error associated with the forecast. We assume that the initial state is Gaussian, that is

$$\xi_0 \rightsquigarrow \mathcal{N}\left(\xi_{0|0}, P_{0|0}\right)$$

Therefore, given the initial values $\xi_{0|0}$ and $P_{0|0}$, Kalman filter recursion is given by

$$\begin{aligned} \xi_{t|t-1} &= \mathbf{T}\xi_{t-1|t-1} + \mathbf{c} \\ P_{t|t-1} &= \mathbf{T}P_{t-1|t-1}\mathbf{T}' + \mathbf{RQR}' \\ Y_{t|t-1} &= \mathbf{Z}_t\xi_{t|t-1} + \mathbf{d} \\ F_t &= \mathbf{Z}_t P_{t|t-1}\mathbf{Z}_t' + \mathbf{H}_t \\ K_t &= P_{t|t-1}\mathbf{Z}_t' F_t^{-1} \\ \xi_{t|t} &= \xi_{t|t-1} + K_t\left(Y_t - Y_{t|t-1}\right) \\ P_{t|t} &= \left(\mathbf{I} - K_t\mathbf{Z}_t\right)P_{t|t-1}\left(\mathbf{I} - K_t\mathbf{Z}_t\right)' + K_t\mathbf{H}_t K_t' \end{aligned}$$

For $t = 1, \dots, T$.

D.2.2 Backward recursion using Gibbs sampling

Forward recursion of Kalman filter in the previous section yields the following sequences of updated and forecasted state variables and variances $\{\xi_{t|t}\}_{t=1}^{T}$, $\{\xi_{t|t-1}\}_{t=1}^{T}$, $\{P_{t|t}\}_{t=1}^{T}$, and $\{P_{t|t-1}\}_{t=1}^{T}$. Define the smoothed estimates, that is the estimates based on all available observations, of states and variances as

$$\begin{aligned} \xi_{t|T} &= E\{\xi_t|Y_T, \mathbf{Z}_T, \mathbf{H}_T, \mathbf{Q}\} \\ P_{t|T} &= E\left\{\left(\xi_t - \xi_{t|T}\right)\left(\xi_t - \xi_{t|T}\right)'\right\} \\ \xi_t &\rightsquigarrow \mathcal{N}\left(\xi_{t|T}, P_{t|T}\right) \end{aligned}$$

Therefore, last entry of updated sequences of state variables and variances, $\xi_{T|T}$ and $P_{T|T}$, are respectively the mean and variance of the smoothed estimate for the final date in the sample. That is, smoothed estimate for T is drawn from

$$\xi_T \rightsquigarrow \mathcal{N}\left(\xi_{T|T}, P_{T|T}\right)$$

Following Carter and Kohn (1994), entire sequences of the smoothed estimates are obtained by moving backward through the sample starting from $t = T - 1$ to $t = 1$ using the following set of equations:

$$\begin{aligned} L_t &= P_{t|t}\mathbf{T}'\left(\mathbf{T}P_{t|t}\mathbf{T}' + \mathbf{RQR}'\right)^{-1} \\ \xi_{t|t+1} &= \xi_{t|t} + L_t\left(\xi_{t+1} - \mathbf{c} - \mathbf{T}\xi_{t|t}\right) \\ P_{t|t+1} &= \left(\mathbf{I} - L_t\mathbf{T}\right)P_{t|t}\left(\mathbf{I} - L_t\mathbf{T}\right)' + L_t\mathbf{RQR}'L_t' \\ \xi_t &\rightsquigarrow \mathcal{N}\left(\xi_{t|t+1}, P_{t|t+1}\right) \end{aligned}$$

D.3 Bayesian inference

The entire sequence of parameters of interest A_t, B_t and Σ_t are estimated by simulating their distribution using Bayesian approach, namely we implement a Gibbs sampler. Simulation is carried out in four steps, simulating in turn time-varying reduced form VAR parameters A_t, contemporaneous coefficients B_t, volatilities Σ_t and variance-covariance matrix V.

D.3.1 Priors

Specifications of prior distribution in this paper follow Primiceri (2005). Initial value for time-varying parameters and variance-covariance matrices are assumed to be mutually independent. An initial subsample of 40 observations is used to generate OLS point estimates of the parameters of interest. Priors of the initial value of the reduced form VAR parameters A_0, the contemporaneous coefficients B_0 and the logarithm of volatilities $\ln(\Sigma_0)$ are assumed to follow a normal distribution with mean equals to the corresponding OLS estimates of the parameter and variance equals to four times the corresponding OLS variance for A_0 and B_0, and equals to the identity matrix for $\ln(\Sigma_0)$.That is,

$$\begin{aligned}\alpha_0 &\rightsquigarrow \mathcal{N}\left(\hat{\alpha}_{ols}, 4\cdot V\left(\hat{\alpha}_{ols}\right)\right)\\ b_0 &\rightsquigarrow \mathcal{N}\left(\hat{b}_{ols}, 4\cdot V\left(\hat{b}_{ols}\right)\right)\\ h_0 &\rightsquigarrow \mathcal{N}\left(\hat{h}_{ols}, \mathbf{I}_n\right)\end{aligned}$$

Priors of different blocks of the variance-covariance matrix V, in turn, are assumed to be independent and to follow an inverted Wishart distribution. That is,

$$\begin{aligned}Q &\rightsquigarrow \mathcal{IW}\left(k_Q^2\cdot 40\cdot V\left(\hat{b}_{ols}\right), 40\right)\\ S_{[i]} &\rightsquigarrow \mathcal{IW}\left(k_S^2\cdot (i+1)\cdot V\left(\hat{b}_{ols}\right), (i+1)\right)\\ W &\rightsquigarrow \mathcal{IW}\left(k_W^2\cdot (n+1)\cdot \mathbf{I}_n, (n+1)\right)\end{aligned}$$

where $k_Q^2 = 0.01$, $k_S^2 = 0.1$, $k_W^2 = 0.01$ and n is the number of endogenous variables in the system. Notice that these priors assumptions together with random walk assumption in (5) imply normal priors on the entire sequences of of A_t, B_t and Σ_t conditional on Q, S and W. Set in this way, as it is explained in Primiceri (2005), priors are not flat, but sufficiently diffuse and uninformative, letting data determine the best estimates of given parameters.

D.3.2 Posterior distribution

Given that the state space models (6), (8) and (11) are linear and Gaussian, posterior distributions of the state variables $\alpha_t|Y_t, B_t, \Sigma_t, S$, $b_t|Y_t, \alpha_t, \Sigma_t, S$ and $h_t|Y_t, \alpha_t, B_t, W$ are generated using forward and backward recursion of Kalman filter developed in 1.1.3. Variance-covariance matrices Q, S and W are generated from their respective independent posterior distributions, which are, assume to follow an inverted Wishart distribution. That is,

$$\begin{aligned}Q|Y_t, A_t, B_t, \Sigma_t &\rightsquigarrow \mathcal{IW}\left(\left(\sum_{t=p+1}^{T}\omega_t\omega_t' + \underline{Q}\right), (T-p+\underline{q})\right)\\ S_{[i]}|Y_t, A_t, B_t, \Sigma_t &\rightsquigarrow \mathcal{IW}\left(\left(\sum_{t=p+1}^{T}\zeta_{[i]t}\zeta_{[i]t}' + \underline{S_{[i]}}\right), \left(T-p+\underline{s_{[i]}}\right)\right)\\ W|Y_t, A_t, B_t, \Sigma_t &\rightsquigarrow \mathcal{IW}\left(\left(\sum_{t=p+1}^{T}\eta_t\eta_t' + \underline{W}\right), (T-p+\underline{w})\right)\end{aligned}$$

where $\underline{Q}$, $\underline{S_{[i]}}$ and W are positive definite scale matrices from the inverted Wishart prior distributions of Q, block matrix $S_{[i]}$ of S and W, and q, $s_{[i]}$, w their respective degree of freedom.

D.3.3 Markov Chain Monte Carlo (MCMC) algorithm

To resume, the Markov Chain Monte Carlo (MCMC) algorithm takes the following form:

1. Specify the initial sequence of A_t, B_t, Σ_t , D_t and V
2. Generate the states α_t conditional on Y_t, B_t, Σ_t and Q using Kalman filter for $t = 1, \ldots, T$
3. Generate off-diagonal elements b_t of the contemporaneous matrix B_t conditional on $Y_t,\ \alpha_t, \Sigma_t$ and *S* using Kalman filter for $t = 1, \ldots, T$
4. Generate volatilities σ_t conditional on $Y_t,\ \alpha_t,\ b_t, D_t$ and W using Kalman filter for $t = 1, \ldots, T$
5. Generate a new selection matrix D_t by sampling from $P(d_{it} = k|Y_{it}^{**}, h_{it})$ conditional on $Y_t, \alpha_t, b_t, \sigma_t$ for $t = 1, \ldots, T$
6. Generate variance-covariance matrix V by sampling from independent inverted Wishart distribution
7. Check for stationnarity of the VAR, and if, only if it is the case, store parameters of interest
8. Go to step 2

It is worth noting that step 7 is implemented in order to insure that realizations of the VAR are stationary and only draws are accepted and stored. Stationnarity is checked by calculating the maximum absolute eigenvalue of the companion matrix corresponding to a VAR(1) representation of VAR(p) at each point in time. If the maximum absolute eigenvalue is strictly lower than unity, VAR are stationary and draws are accepted.

E. Convergence Diagnostic

In order to assess convergence of the sample to the posterior distribution, we perform a set of standard convergence diagnostic tests namely the autocorrelation function and the Raferty and Lewis (1995) MCMC diagnostics (numbers of draws and I-statistic).[9] All figures are subdivided in three parts and depict respectively the convergence diagnostic tests for the lag-coefficients (α_t) of the model (2), the contemporaneous coefficients (b_t) and the (log) standard error coefficients (h_t). The unit of x-axis correponds to the number of estimated coefficients for all time periods. For instance, the number 2225 (=5x445) corresponds to the estimated values of the (log) standard error coefficients

[9] We used a modified Matlab version code of James P. Lesage to implement the convergence diagnostic tests.

$h_t = \left(h_t^{usd}, h_t^{hwwi}, h_t^{gold}, h_t^{drycargo}, h_t^{brent}\right)$ for the period 1976M7 to 2013M7. In sum, convergence diagnostic results seem satisfactory.

E.1 Autocorrelation function

It is a common practice to calculate first the autocorrelation function in order to measure the independence of the sequence of the draws. Figure 7 depicts the autocorrelation at lags 1, 5, 10 and 50. Autocorrelation of the VAR (α_t) and contemporaneous coefficients (b_t) are smaller than 0.2 except for some exceptions, indicating independence of the sequence of the draws. The same conclusion can be made for the standard error coefficients where the autocorrelation at lags 5, 10 and 50 are smaller than 0.6 (for the majority, the plots are below 0.4).

[Insert Figure 7 here]

E.2 Raferty-Lewis diagnostics

Raferty and Lewis (1995)[10] proposed a diagnostic test that permits to calculate the total number of draws needed to achieve a certain level of accuracy (Ntot) and the minimum number of draws that would be needed if the draws represented an i.i.d chain (Nmin). Raferty and Lewis number of draws in Figure 8 indicates that for all coefficients, the total number of draws needed to achieve a certain degree of accuracy is less than 200.

[Insert Figure 8 here]

The Raferty and Lewis (1995) I-statistic is the ratio of the total number of draws needed to acheive a certain level of accuracy (Ntot) to the minimum number of draws that would be needed if the draws represented an i.i.d chain (Nmin). Values of I-stat exceeding 5 indicate a convergence problem. Figure 9 indicates that the Raferty and Lewis I-STAT for all coefficients are less than 2.

[Insert Figure 9 here]

[10] Parameters value used to implement the Raferty and Lewis (1995) diagnostic tests are defined as follows : the quintile of the marginal posteriori is set to be equal to 0.025, the minimum probability needed to achieve the required accuracy to 0.95, and the desired accuracy to 0.005.

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