NOTA DI LAVORO

110.2014

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Energy: Resources and Markets
Series Editor: Giuseppe Sammarco

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Summary

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JEL Classification: C32, C58, E44, Q41, Q43

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1. Introduction

We investigate the response of stock market volatility to oil shocks. From a casual reading of market commentaries, the business community seems to have clearly identified both causes and consequences of oil price shocks[1]. Focusing on the crude oil-stock market nexus, there is a shared belief that oil price shocks can depress asset prices and boost volatility (see e.g. Chisholm, 2014; Kinahan 2014; Regan, 2014). As for the causes, commentators concentrate mainly on oil supply interruptions, or the fear thereof, due to political unrests in the Middle East, and often the price of oil is considered as exogenous with respect to macroeconomic and financial conditions[2].

On the contrary, most academics would agree that the price of crude oil is endogenous[3] (Kilian, 2008b) and that it is driven by combination of demand and supply side innovations (Hamilton, 2013). However, the channels of transmission of energy price shocks and their impacts on macroeconomic and financial variables remain topics for research and debate (Blanchard and Galí, 2009; Blinder and Rudd, 2013; Lee et al., 2011; Serletis and Elder, 2011). The intensity of disagreement is particularly high in the strand of the literature focusing on the impact of oil shocks on the stock market (see Chen et al., 1986; Huang et al., 1996; Jones and Kaul, 1996; Sadorosky, 1999; Wei, 2003). Early analyses have two features in common: the price of oil is treated as exogenous and the causes underlying oil shocks are not identified. More recently, relying on the work of Kilian (2009), many studies have acknowledged

[1] For the majority of commentators the "prime suspects" for oil price run-ups are supply disruptions due to political unrests in the Middle East (see e.g. Chisholm, 2014; Jakobsen, 2014; Kinahan, 2014; Saelensminde, 2014; Tverberg, 2010). Oil price shocks are associated to growth reductions (Jakobsen, 2014), inflationary pressures (Frisby, 2013; Saelensminde, 2014), debt defaults (Tverberg, 2010), systemic risk (Froggatt and Lahn, 2010), depressing effects for the bond and the stock market (Frisby, 2013; Jakobsen, 2013; Regan, 2014; Saelensminde, 2014), as well as to volatility and uncertainty shocks (Froggatt and Lahn, 2010; Chisholm, 2014; Kinahan, 2014). For a more comprehensive view, which acknowledges the existence of shocks originating from both the supply and the demand side of the oil market, see The Economist (2012).

[2] A case in point is Saelensminde (2014), who motivates why investors should hedge their equity portfolio against geopolitical risk, as proxied by the price of energy, with the following example: "high oil prices lead to higher inflation; high inflation trashes currencies and sends central bank rates higher. High energy costs, higher interest rates and inflation: a deadly combination for economies and stock markets. Stock markets crash, everyone feels poorer, bad debt explosions cause another banking crisis - confidence is sapped and hey presto, we're back in 2008!"

[3] See Blanchard and Galí (2009) and Blinder and Rudd (2013) for the alternative view that considers the price of oil as exogenous.

that it is crucial whether a given oil price change has been generated by demand or supply pressures. In other words, the responses of stock prices (Abhyankar et al., 2013; Güntner, 2013; Kilian and Park, 2009; Kang and Ratti, 2013*a*), dividend yield components (Chortareas and Noikokyris, 2014), and volatility (Degiannakis et al., 2014) depend on the origin of the oil price shock. These results are not limited to the stock market. Actually, existing studies have confirmed that disentangling the causes underlying oil price shocks is important for explaining the response of many other variables, such as U.S. real GDP and price level (Kilian, 2009), bond returns (Kang et al., 2014) and macroeconomic uncertainty (Kang and Ratti, 2013*a,b*). Moreover, these findings are not confined to the U.S., rather they hold also in international comparisons (see e.g. Abhyankar et al., 2013; Baumeister et al. 2010, Degiannakis et al., 2014; Güntner, 2013; Kang and Ratti, 2013a; Kilian et al., 2009).

We build on the work of Kilian (2009) to analyze the impact of oil shocks on stocks market volatility. Changes in the real price of crude oil are modeled as arising from three different sources: shocks to the supply of crude oil, to the aggregate demand for all industrial commodities and to oil-specific demand. Kilian's structural VAR is used to describe the global market for crude oil and to estimate the structural innovations that drive its price. These shocks are then employed to investigate the response of stock market volatility to oil price shocks deriving from different sources. More precisely, we answer a number of questions. Does U.S. stock market volatility react to oil shocks? Is the response to shocks arising from the supply and demand side of the crude oil market different? What is the volatility response to oil shocks for industry portfolios? Do net oil importers and net oil exporters experience oil shocks differently?

We show that on average, over the period 1975-2013, the U.S. stock market volatility has responded mainly to oil price shocks originating from the demand side. Investors interpret oil price hikes generated by unexpected increases in the aggregate demand for all industrial commodities, including crude oil, as good news, therefore the volatility response is negative in the short-run. On the contrary,

shocks due to sudden increases in the precautionary demand for crude oil tend to boost volatility. Supply side oil shocks have virtually no impact on volatility. Robustness checks show that these results are not affected by changes to the model specification, to the sampling frequency of the data or to the volatility proxy. Moreover, our results do not depend on the choice of using the structural residuals from a VAR to measure oil supply and oil-specific demand shocks.

Consistently, the results obtained at the U.S. aggregate stock market level show that the responses of the volatility of shares belonging to different industries, as well as the volatility of the stock markets in different countries, vary depending on the cause underlying the oil shock. On the contrary, country and industry differences are modest.

This study is related to the analysis of Degiannakis et al. (2014), who study the response of volatility to oil shocks using the model by Kilian (2009). However, these authors focus on the European stock market, use a shorter sample period (1999-2010), and find that volatility reacts only to unexpected changes in aggregate demand, leaving no role for supply-side and oil-specific demand shocks.

The rest of the paper is organized as follows. Section 2 reviews the literature and sketches the theoretical link between volatility and oil shocks. Data and empirical methods are described in Section 3, while Sections 4 and 5 present the empirical results and some robustness checks. Section 6 concludes.

2. Stock market volatility, oil shocks and the macroeconomy

The theoretical relationship between oil price shocks and stock market volatility can be sketched by relying on the log-linearization of Campbell (1991), according to which unexpected returns are related to innovations to dividend growth rates (or cash flow news) and expected returns (risk premiums or discount rates). Innovations to dividend growth rates have a positive effect on unexpected returns, while shocks to interest rates or risk premiums have a negative impact.

If innovations to cash flow and expected returns were observable, the relationship between unexpected stock returns, expected stock returns and cash flow news could be used to disentangle the relative contribution of each component to unconditional stock variances. In practice, these components are often estimated from the data by regressing stock returns on a set of predictor variables that proxy the state of the real and the financial side of the economy (see e.g. Campbell, 1991; Hollifield et al., 2003). As a consequence, the variance of unexpected stock returns, proxied by their realized volatility, can be related to a set of macroeconomic and financial control variables, including oil price shocks (Engle and Rangel, 2008). Applications of the log-linearization to assess the impact of oil shocks on the stock market include Abhyankar et al. (2013), Chortareas and Noikokyris (2014), and Kilian and Park (2009).

To the extent that oil price shocks affect the level of uncertainty about future macroeconomic and financial conditions, they will influence volatility via their impact on cash flows, interest rates or risk premia. We do not attempt to discriminate between these different channels of transmission, however it is useful to briefly review some empirical regularities about stock market volatility.

Focusing on the real side of the economy, Schwert (1989) highlights that stock volatility rises during contractions and falls during expansions, although the linkage between macroeconomic volatility and financial volatility is quite weak. The countercyclical behavior of financial volatility is confirmed also by Corradi et al. (2013). These authors develop a no-arbitrage model where stock market volatility is related to macroeconomic and unobservable factors and find that the first set of variables can explain a large fraction of stock volatility. Focusing on growth rates and volatilities of PPI inflation and industrial production, Engle et al. (2013) find that macroeconomic fundamentals play an important role in forecasting volatility, both at short and long horizons. Paye (2012) shows that, although variables related to macroeconomic uncertainty Granger-cause realized stock market volatility, out-of-sample forecasts which exploit such variables are as accurate as those based on purely time series models.

Similar results have been obtained by Christiansen et al. (2012), who focus on the volatility of equities, foreign exchange, bonds and commodities. Engle and Rangel (2008) develop the Spline-GARCH model which is used to extract a low-frequency volatility component. Considering a cross-sectional analysis for 48 international stock markets, they show that the volatility of macroeconomic fundamentals is positively correlated with the low-frequency volatility component. In another cross-sectional analysis Diebold and Yilmaz (2010) find that stock market volatility and GDP volatility are positively and significantly correlated.

A second key finding, highlighted by Bloom (2014), is that news have an asymmetric impact. More precisely, bad events generally increase uncertainty, while good news rarely cause uncertainty shocks. This fact, coupled with the evidence in Kilian (2009) that the effects of an oil price shock depend on its underlying causes, suggests that it is not sufficient to consider the relationship between stock volatility and oil price changes. In fact, it is reasonable to expect that price increases generated by sudden increases to the aggregate demand for industrial commodities will be interpreted as good news and reduce stock market volatility, at least in the short-run. On the other hand, shocks arising from production shortfalls, or from concerns of a conflict in an oil producing country, will probably increase the level of volatility.

3. Data and empirical methods

3.1 Data

The volatility of the U.S. stock market is measured using the closing daily prices for the S&P500 index sourced from Yahoo! finance. However, since there are reasons to believe that different industries might experience different reactions to oil price shocks, for instance because of heterogeneity in the level of energy intensity, we also consider a set of portfolios containing shares of firms in the same

sector. For this part of the analysis, we use the data available on the website of Ken French, who provides daily returns for 49 industries[4].

Realized volatility (*RV*) is used to proxy the variability of stock price indices. In line with Schwert (1989), *RV* is calculated as the sum of the squares of daily real log-returns:

$$RV_t = \sum_{k=1}^{N_t} r_{j:t}^2 \quad (1)$$

where N_t and $r_{j:t}$ are the number of days and daily real log returns in month *t*. All empirical results are based on annualized realized standard deviation, defined as $(252 \times RV_t)^{1/2}$, although for brevity we keep on using *RV* thereafter.

3.2 Structural oil shocks: identification & estimation

Changes in the real price of oil deriving from shocks to oil supply, aggregate and oil-specific demand can be retrieved from the structural VAR model of Kilian (2009). The model describes the global market for crude oil using three variables: the annualized percent change in world crude oil production, $\Delta prod_t$, an index of real economic activity, rea_t, and the real price of oil, rpo_t [5]. Data are monthly and the sample period runs from February 1973 until December 2013.

The (3×1) vector structural innovations, $\boldsymbol{\upsilon}_t$, can be retrieved from covariance matrix of reduced-form residuals, $\boldsymbol{\varepsilon}_t$, by imposing a set of exclusion restrictions:

[4] See http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data library.html, for details. The construction of real returns on portfolios and on the S&P500 follows Lunde and Timmermann (2005). We linearly interpolate monthly CPI data such that the resulting daily CPI variable grows at constant rate through the month. The end-of-month observation of the daily CPI variable is thus equal to the corresponding value of the monthly CPI series. The price index used is the CPI for All Urban Consumers, as reported by the Bureau of Labor Statistics (mnemonic: CPIAUCSL).

[5] $\Delta prod_t$, the annualized percent change in world crude oil production, is defined as $1200 \times \ln(prod_t/prod_{t-1})$. World oil production, $prod_t$, is available starting from January 1973 in the U.S. Energy Information Administration's Monthly Energy Review (Table 11.1b). The index of real economic activity, rea_t, introduced by Kilian (2009), is based on dry cargo ocean shipping rates and is available on the website of the author. It is used to proxy monthly changes in the world demand for industrial commodities, including crude oil. The real price of crude oil, rpo_t, is the refiner's acquisition cost of imported crude oil and it is available from the U.S. Energy Information Administration (EIA). Deflation is carried out using the CPI for All Urban Consumers, as reported by the Bureau of Labor Statistics (mnemonic: CPIAUCSL). The deflated price is in logarithms and then is expressed in deviations from its sample average.

$$\begin{pmatrix} \varepsilon_t^{\Delta prod} \\ \varepsilon_t^{rea} \\ \varepsilon_t^{rpo} \end{pmatrix} = \begin{pmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{31} & a_{33} \end{pmatrix}^{-1} \begin{pmatrix} \upsilon_t^{oil\ supply\ shock} \\ \upsilon_t^{aggregate\ demand\ shock} \\ \upsilon_t^{oil\ demand\ shock} \end{pmatrix} \quad (2)$$

These identifying restrictions are consistent with a global market of crude oil characterized by a vertical short-run supply curve and a downward sloping short-run demand curve. Oil supply does not respond within the month to changes in oil demand and only does it shift in response to changes in production due to exogenous events, such as conflicts in the Middle East. Oil demand is driven by the remaining structural innovations. Aggregate demand shocks capture shifts in the demand for all industrial commodities, including crude oil, associated to the global business cycle. The zero restriction in the second row of expression (2) implies that oil specific demand shocks influence the global business cycle only with a delay. The last structural shock, i.e. oil-specific demand innovations, is designed to capture changes in the price of oil driven by shifts in the precautionary demand arising from uncertainty about the future availability of crude oil. Therefore, the real price of oil changes instantaneously in response to both aggregate and oil-specific demand shocks, as well as in response oil supply shocks.

In practice, estimates of the structural shocks, denoted as $\mathbf{u}_t$, are obtained from OLS estimates of the reduced-form of a VAR model of order 24.[6]

3.3 Estimating the impact of oil shocks on volatility

The theoretical relationship between oil shocks and volatility sketched in Section 2 can be empirically implemented with VAR model for $\mathbf{x}^i_t = [u^i_t, RV_t]^T$, i = 1, 2, 3. Elements of the estimated structural residuals vectors from Kilian's VAR, $\mathbf{u}_t$, are denoted as u^i_t

[6] A more detailed description of the Kilian (2009) model and a plot of the estimated structural shocks are provided in the Appendix to our paper.

Estimation of the response of volatility to oil shocks originating from the supply and the demand side of the crude oil market is based on a recursively identified VAR for $\mathbf{x}^i_t$ with the *i*-th oil shock ordered first. This identification scheme relies on the assumption that innovations to the price of crude oil are predetermined with respect to macroeconomic and financial aggregates. In other words, while the price of crude oil can respond to all past information, predeterminedness implies the absence of an instantaneous feedback from *RV* to oil shocks u^i_t. This working hypothesis has been used extensively used in the literature (see Kilian 2008*b* and references therein) and is also empirically supported by the results of Kilian and Vega (2011).

The analysis is implemented in two steps. First, we use monthly data from February 1973 until December 2013 to estimate the three oil shock series using a VAR of order 24 and the identification scheme of Kilian (2009). This delivers structural residuals running February 1975 until December 2013. Next, we estimate three recursively identified bivariate VAR models including *RV* and one of the oil shocks u^i_t. Impulse responses are derived from VAR models of order 12. While this lag order is sufficient to fully capture the dynamics of monthly *RV*, we have also experimented with VAR models of order 18 and 24. Since results based on higher order VAR models are almost identical, we will only present results based on twelve monthly lags.

4 Empirical results

4.1 The impact of oil shocks on the volatility of the U.S. stock market

One of the key results of Kilian (2009) is that, at each point in time, shocks to the real price of crude oil are the result of disturbances originating both from the supply and the demand sides of the market. For instance, the volatility of supply side innovations has decreased through time, and supply shocks seem to have no role in explaining the surge in the price of oil in 2008, nor the increase of the volatility during the recent financial crisis. This fact is at odd with the majority of the market commentaries,

where a direct causal link between volatility and political events in the Middle East is often postulated, while little, if any, role is attributed to oil shocks arising from the demand side. A case in point is Kinahan (2014), who reports that: "the market's drop - triggered by higher oil prices and the potential for greater oil supply disturbances in Iraq - stirred investor risk perception. As evidence the CBOE Volatility Index,…, hit 12.56 on June 12".

[FIGURE 1 HERE]

Responses of the U.S. stock market volatility to a (one-standard deviation) shock to the supply and demand of crude oil are shown in Figure 1. Each panel shows the estimated impulse response function (IRF) together with one and two-standard error bands based on the recursive-design wild bootstrap of Gonçalves and Kilian (2004). Henceforth, oil shocks will represent unpredictable reduction to the supply crude oil and unpredictable aggregate or oil-specific demand increases. In other words, all shocks have been normalized such that their expected effect is to generate an increase in the price of crude oil.

As it can been seen from a joint inspection of the plots in Figure 1, on average over the 1978-2014 period the U.S. stock volatility has responded mostly to oil price shocks originating from the demand side of the oil market, while supply-driven shocks have had hardly any impact.

The leftmost graph shows that, contrarily to what asserted in the majority of market commentaries, shocks to the supply of crude oil have no impact on volatility: the impulse response function is always close to zero and statistically nil.

From the graph in the middle we see that an unanticipated increase of the aggregate demand for industrial commodities yields an immediate decrease in stock market volatility, which is also marginally significant. The negative sign of the volatility response is consistent with financial markets interpreting an increase in the demand for industrial commodities as good news. After six months, the volatility response gets close to zero, while after twelve months the sign of the response becomes

positive, thus indicating an overshooting in the reaction of volatility to unexpected changes in aggregate demand. Even though the positive response is statistically insignificant, the switch in the sign of the IRF might indicate that, if the increased demand for crude oil is perceived as permanent, investors will start worrying about the sustainability of such higher level of demand.

The response of volatility to a shock to the precautionary demand for crude oil is presented in the graph on the right. Similarly to shocks to aggregate demand, the impact response of volatility to increases in oil-specific demand is negative. However, after a semester the response of volatility becomes positive and statistically significant. The delayed volatility boosting effect of increased oil-specific demand could be explained by recalling that shocks to precautionary demand for oil are basically shocks to the expectations about future oil supply. Therefore, a sustained higher precautionary demand could indicate greater macroeconomic uncertainty, which is clearly reflected in a more volatile stock market.

Overall, the three impulse response functions are consistent with the view that the origin of the oil price shock matters for explaining the response macroeconomic and financial variables (Abhyankar et al. 2013; Chortareas and Noikokyris, 2014; Degiannakis et al. 2014; Güntner, 2013; Kilian, 2009; Kilian and Park, 2009; Kang and Ratti 2013a,b; Kang et al., 2014). In the case of volatility, this implies that, if investors know what has originated an increase in the price of oil, they can optimize their risk management and asset allocation strategies accordingly.

Moreover, to the extent that stock market volatility can be interpreted as index of macroeconomic uncertainty, our results are line with the survey of Bloom (2014), who highlights that news have an asymmetric impact on uncertainty. Oil price hikes generated by sudden increases to the world demand for all industrial commodities are signals of improved business conditions that, being good news, tend to reduce volatility. Shocks to the physical supply of crude oil, or to oil-specific demand, indicate a higher degree of macroeconomic uncertainty and are interpreted as bad news. We have shown that on average, over the 1978-2013 sample period, the only bad news that significantly increases volatility is

due to unexpected increases in the precautionary demand for crude oil. The lack of response of stock volatility to oil supply shocks can be explained in terms of the temporary and limited response of the real price of oil to shocks from the supply side of the oil market (Kilian, 2009). Moreover, investors are aware that many geopolitical events in the Middle East are not associated to actual reductions in the supply of crude oil, since they are often compensated by production increases in other oil-producing countries (see, e.g. the Iranian revolution). Therefore, to the extent that shocks to the supply of crude do not reduce the long-run profitability of corporate investments, investors' plans will be unaffected (Güntner, 2013).

These results are consistent with those of Kang and Ratti (2013a,b), who report very similar impulse response functions for an index of policy uncertainty. Compared with Degiannakis et al. (2014), who study the impact of oil shocks on the volatility of the European stocks, our analysis leads to different conclusions. These authors show that the impact of oil price shocks due to unanticipated supply reductions or oil-specific demand increases is negligible. While these results can be partially explained by the differences in the fundamentals driving the price of stocks in the U.S. and European markets, the empirical methodology followed by the authors should be also considered.

Specifically, the reduced-form of the VAR of Degiannakis et al. (2014) includes four lags on the same variables, namely production and global activity, used in our study as well as in Kilian (2009), while the global price of oil is represented by (the nominal log-return on) the price of Brent. There are at least three points that deserve attention. First, the choice of using Brent instead of RAC to represent global price of oil might be questionable (see section 2 in Kilian et al., 2013). In fact, while world oil production is growing, the production of oil in the North Sea, as measured by field production in Norway and U.K., is falling, after reaching a peak in 1999[7]. Therefore, the choice of using Brent

[7] See Hamilton (2013) for a more detailed discussion. Over the sample period considered by Degiannakis et al. (2014) the share of world oil production from North Sea fields has fallen from 8.6% in 1999 to 4.2% in 2010. The average annual

together with world production data does not seem consistent. Moreover, as illustrated by Bastianin et al. (2014) among others, it is not clear a priori whether the price of Brent can serve as a benchmark for the price oil.

The inclusion of first differenced log-prices in the VAR might also be questionable. As highlighted by Kilian (2010, p. 97), "economic theory suggests a link between cyclical fluctuations in global real activity and the real price of oil (….). Differencing the real price series would remove that slow-moving component and eliminate any chance of detecting persistent effects of global aggregate demand shocks". Degiannakis et al. (2014, p. 42) justify the choice of including the log-differenced price on the basis of unit-root pre-testing. However, since tests for a unit root have low power against the local alternative of a root close to (but below) unity (Cochrane, 1991), over-differencing might lead to impulse response functions with poor confidence interval coverage (Ashley and Verbrugge, 2009). Moreover, as Gospodinov et al. (2013) have shown, in the presence of uncertainty about the magnitude of the largest roots, a VAR in levels, as opposed to a VAR in first-differences, appears to be the most robust specification.

A third potential pitfall in the specification of Degiannakis et al. (2014) is the use of only four lags. As pointed out by Kang and Ratti (2013a), long lags are important in structural models of the global oil market to account for the low frequency co-movement between the real price of oil and global economic activity. Moreover, when working with monthly data, including less than 12 lags might be problematic if the series are characterized by seasonality (see Günter, 2013). A case in point is the monthly world production time series that the authors use in their model.

4.2 Does the impact of oil shocks vary across industries?

growth rate is -4.8% for North Sea fields and 0.9% for world oil production, respectively (based on annual data from EIA, Monthly Energy Review, Table 11.1b).

Economists have proposed many explanations of how oil price shocks are transmitted to the economy and to the stock market (see e.g. Baumeister et al. 2010; Lee et al. 2010). For instance, oil price shocks might have direct input-costs effects: higher energy prices reduce the usage of oil and hence lower the productivity of capital and labor. Alternatively, if higher energy prices lower the disposable income of consumers, the transmission is due to an income effect that reduces the demand for goods. In any case, these alterative channels of transmission suggest that the response of volatility might be different across different industries. Heterogeneous responses might depend either on the level of energy intensity, or on the nature of the good produced or service provided.

We focus on the volatility of four industry portfolios selected among the 49 provided by Ken French, namely: oil & gas, precious metals, automobile and retail. The shares of firms in the oil & gas and automotive industry should be very sensitive to the price of crude oil. Oil & gas companies have the most energy intensive production processes. The volatility of the shares of auto producers is interesting because car sales and, more generally, the purchase of durable goods might be delayed if oil price is high or expected to be high. The rationale for including the retail industry is that with more expensive crude oil consumers have to spend more to fuel their cars and are thus left with less money to purchase other goods. Firms in the precious metal industry have been considered because it is believed that investors will tend to buy more gold and silver (safe-haven assets) when the level of political uncertainty is high. Moreover, the choice of these four industries allows to compare our results with those of Kilian and Park (2009) and Kang and Ratti (2013a).

[FIGURE 2]

The first noticeable result from Figure 2 is the shape of the estimated IRFs to any of the three oil shocks, which is similar across industries. On the contrary, the responses change depending on the cause underlying the oil shock.

Shocks to the supply of crude oil boost the stock volatility of the firms operating in the precious metal industry on impact and generate a positive response that lasts for almost a year.

Petroleum & natural gas companies, which constitute the most energy intensive industry, do not experience a significant volatility change in response to oil shocks generated by a supply shortfalls. The same comment applies to shares in the automobile and retail portfolios.

Sudden increases in the aggregate demand for all industrial commodities yield volatility responses which are almost identical across industries. The volatility of all portfolios drops on impact and remains at a lower level for about six months, thus suggesting that investors interpret expansions of the world aggregate demand as good news. After a year from the shock, the volatility of oil & gas shares experiences an increase, which suggests that investors get worried about the long-term sustainability of the increased demand for crude oil.

Independently of the industry, an unexpected increase in oil-specific demand yields volatility responses that are generally negative and statistically insignificant on impact, while positive after at least a quarter. The volatility increase generated by a shock to the precautionary demand for crude is easily rationalized. Since it is a proxy of a shock to the expectations about the future availability of oil, an unexpected increase in the precautionary demand for oil indicates a higher degree of political and macroeconomic uncertainty.

All in all, these results highlight that supposed link between volatility responses and energy intensity of the industry is virtually inexistent. As an example, the magnitude and the shape of the responses of the oil & gas portfolio are not very different from those of other, less energy intense, industries.

This finding is consistent with Kilian and Park (2009), as well as with Kang and Ratti (2013a), who have analyzed the response of cumulative returns on the same set of portfolios. Their results show that a given shock can have very different impacts on the value of stocks depending on the industry and on underlying causes of the oil price increase. One noticeable difference is that our analysis shows that

only the origin of the shock matters, whereas the volatility response to the same shock is very similar across industries, although with a different timing. These results suggest that investors and risk managers should be aware of the causes underlying the oil shock to optimally adjust their portfolios.

4.3 Does the impact of oil shocks vary across countries?

Since the literature has shown that economies with different characteristics will respond differently to oil shocks (Abhyankar et al., 2013; Baumeister et al. 2010, Degiannakis et al., 2014; Güntner, 2013; Kang and Ratti, 2013a; Kilian et al., 2009; Schwert, 2011), this section is devoted to a small-scale international comparison which involves Japan, Norway and Canada. As of 2010, the U.S. and Japan were the first and third largest crude oil net-importers, while Norway and Canada were ranked ninth and eighteenth among net-exporters[8]. These countries have been chosen because of data availability and to allow comparison with the existing literature (see, among others, Güntner, 2013, and Kang and Ratti, 2013a).

The stock market *RV* of these countries has been calculated using real returns on their market indices: Nikkei for Japan, S&P/TSX Composite for Canada and the Oslo Børs Benchmark, OBX, for Norway.

Since stock market indices are denominated in local currency, while the price of crude oil entering Kilian's SVAR is denominated in U.S. dollars, we take the fluctuations of exchange rates into account. In doing so, we follow Güntner (2013) and convert the refiners' acquisition cost of crude oil from U.S. dollars to domestic currency using bilateral exchange rates. After deflating the price of crude oil, we

[8] We calculated net-exports as the difference between exports and imports of crude oil, including lease condensate using the International Energy Statistics published by the Energy Information Administration. Using these data, the four most important net-importers of crude oil in 2010 were: the U.S. (9172 thousand barrels/day), China (4693 thousand barrels/day), Japan (3473 thousand barrels/day), India (3272 thousand barrels/day). The 2010 ranking of net-exporters is as follows: Saudi Arabia (6844 thousand barrels/day), Russia (4856 thousand barrels/day), Iran (2362 thousand barrels/day), Nigeria (2341 thousand barrels/day). Norway and Canada net exports amount to 1590 and 679 thousand barrels per day, respectively. The selection of the countries included in the analysis has been driven by data availability, in fact finding a sufficiently long span of daily and monthly data, especially for other net-exporters, is hardly possible. See also Güntner (2013) on this point.

estimate the VAR for each country and retrieve the corresponding structural shocks[9]. These are subsequently included, along with the corresponding *RV*, in recursively identified bivariate VAR models. While, due to data availability, the sample of the analysis is now limited to the period January 1988-December 2013, the analysis follows the procedure described in Section 3.3.

[FIGURE 3]

The leftmost column of the graphs reported in Figure 3 shows that a supply shock boosts the volatility of the stock market in all countries, with only modest differences between net-importers and net-exporters. On average, over the 1988-2013 sample period, the response of *RV* to an unexpected negative change of oil supply is positive for all countries. These estimates are however marginally significant, and only during the first quarter after the shock. The timing and the persistence of the volatility increase is slightly different across countries: in Canada and Norway the response of volatility remains positive, although modest in value, for over a year, while in the U.S. and Japan it falls back to zero within nine months.

Unexpected changes in global real activity, presented in the second column of Figure 3, are in all cases associated with immediate marginally significant volatility decreases that last up to six months. During the first quarter after an unexpected increase in oil-specific demand, the volatility of all stock markets decreases. One explanation for this behavior is that when the price of crude oil is triggered by higher demand, investors are not sure of whether the additional demand will serve to increase production, or if it contributes to build up inventories to face future supply shortages. Within five months from the precautionary demand shock, the initial volatility drop becomes statistically insignificant in all countries but Canada and the U.S., where the IRFs switch from negative to positive. The new, higher

[9] Daily closing prices of the market indices have been downloaded from Yahoo! finance. Exchange rates have been downloaded from the Board of Governors of the Federal Reserve System, while the CPI for all items for the U.S., Japan and Canada are provided by the OECD - Main Economic Indicators.

level of volatility reached in these countries is temporary for the U.S. and persistent for Canada. Interestingly, after a year also the U.S., Japan and Norway experience a new volatility increase.

Consistently with Güntner (2013) and Kang and Ratti (2013a), our results highlight the importance of disentangling supply and demand oil shock for investing internationally diversified portfolios. However, contrarily to what happens to real stock prices, the response of volatility across countries does not show significant differences.

It is worth noticing that in this section the analysis for the U.S. has been conducted on a sample of data starting in 1988. The main difference between this sample and the longer sample used in Section 4.1 is the response of the U.S. volatility to supply shocks. For the longer sample, the estimated IRF in Figure 1 is always statistically nil, while in Figure 3 the response is positive and marginally significant.

5. Robustness checks

5.1 Alternative oil shock proxies

Our results show that on average, over the sample February 1975-December 2013, the volatility of the U.S. stock market has been resilient to oil price increases driven by supply interruptions. Since supply-driven oil price shocks are often seen as the main channels through which the adverse effects of higher energy prices are transmitted to the economy, this result should be subject of additional investigation. On this respect, we replace the oil supply shock series derived from the structural VAR with the variable developed by Kilian (2008a), who proposes to use production data for measuring exogenous shocks to the supply of crude oil due geo-political events in the OPEC countries[10]. As shown in the top panel of Figure 4, the response of volatility is similar, that is limited and statistically insignificant most of the time.

[FIGURE 4 HERE]

[10] The construction of this alternative oil supply shock has followed the detailed description provided by Kilian (2008a). The empirical methodology is the same as before. See Section 3.3.

As a second robustness check, we consider an alternative measure for the oil-specific shock. Following Ramey and Vine (2010), we use the proportion of respondents to the University of Michigan's Survey of Consumer Sentiment, who cite the price of gasoline, or possible fuel shortages, as a reason for poor car-buying conditions. The graph on the bottom of Figure 4 shows that the volatility response estimated with this alternative proxy is very similar to what obtained when considering shocks to the precautionary demand for crude oil derived from the structural VAR of Kilian (2009).

5.2 Alternative models and distributional assumptions

Our analysis is based on the assumption that innovations to the price of oil are predetermined with respect to macroeconomic and financial conditions. This working hypothesis is however consistent many alternative econometric specification. Among these alternatives, we consider a Distributed Lag (DL) model, since its use to study the impact of oil shocks on macroeconomic aggregates is common in the literature (see, among others, Kilian et al. 2009, Kilian 2008a, 2009).

[FIGURE 5]

We select three DL models of order 15, one for each oil shock, to match the horizon of the IRF presented so far. Moreover, we work also with the log of *RV* as an alternative specification of the dependent variable. Since aggregate stock return volatility is positively skewed and leptokurtotic, researchers often use the logarithm of realized volatility (see Paye, 2010 and references therein). The graphs on the top of Figure 5 show that considering a DL model instead of a recursively identified VAR does not affect the pattern of the estimated responses. The same holds true when a DL model with the log of RV as dependent variable is estimated.

Further robustness checks presented in the Appendix involve the sampling frequency of data, as well as the use of alternative volatility proxies. Results do no change when working with quarterly data, nor when a GARCH model or the CBOE volatility index (VIX) is used in place of RV.

6. Conclusions

Stock volatility and the price of crude oil, being two of the variables that policy makers track most closely (see e.g. Bernanke, 2006; Brown and Sarkozy, 2009), are often front page news. Moreover, both the popular press and academic research have analyzed in detail the effects of oil price shocks on macroeconomic and financial variables.

In this paper we have shown that, in order to understand the response of the U.S. stock market volatility to changes in the price of crude oil, the causes underlying oil price shocks should be disentangled. This conclusion has been extended to the analysis of the impacts of oil price shocks on the aggregate stock market volatility of countries different from the U.S., and of different industry portfolios. Contrarily to what expected, the impact of supply shortfalls is negligible and volatility responds mostly to shocks hitting aggregate and oil-specific demand. Evidence of heterogeneous volatility responses across countries and industries is modest at best.

The empirical methods used in this paper do not incorporate neither time-varying parameters, nor changes in the volatility of the structural shocks, that would be useful to describe evolutions in the structure of the crude oil market and the U.S. economy. Recall that our identification scheme rests on assumption that oil shocks are predetermined with respect to the macroeconomy, therefore the estimated IRFs depend on the composition of the underlying oil shocks and cannot be used to interpret specific historical episodes. Notwithstanding these limitations, these estimates are asymptotically valid and can be interpreted as the average response over the sample period (Kilian, 2008b).

The result that stock volatility reacts differently to shocks originating from the supply and demand side of the crude oil market has important implications for policy makers, investors, macroeconomic model builders, risk managers and asset allocation strategists. For instance, studies on the relation between monetary policy and asset price volatility (e.g. Bernanke and Gentler, 1999), should be extended to

include different oil price shocks, in order to optimize the monetary policy response to changes in volatility originating from either the oil supply or oil demand shocks. Moreover, disentangling the causes of oil price shocks and a deeper understanding of their impacts on volatility are useful exercises to formulate Dynamic Stochastic General Equilibrium models with time-varying second moments (see e.g. Fernández-Villaverde and Rubio-Ramírez, 2010).

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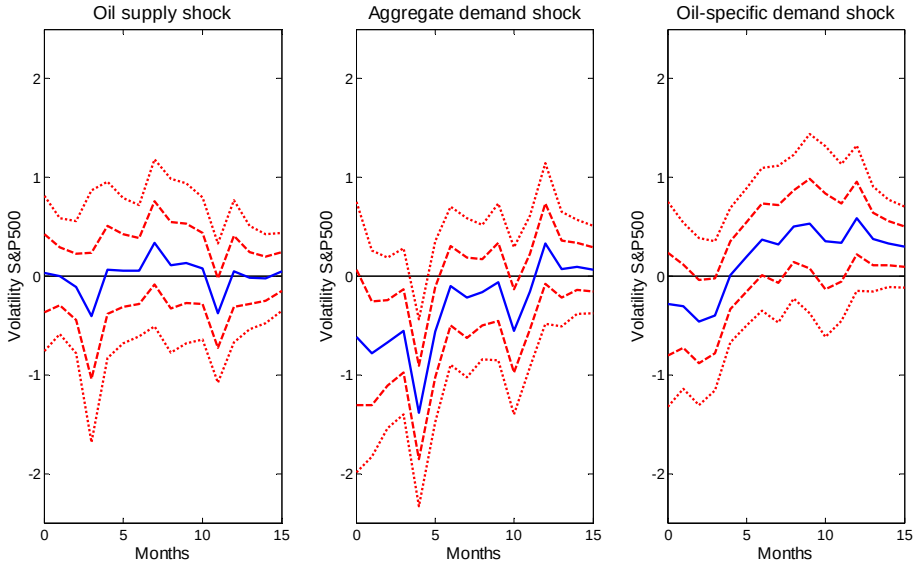
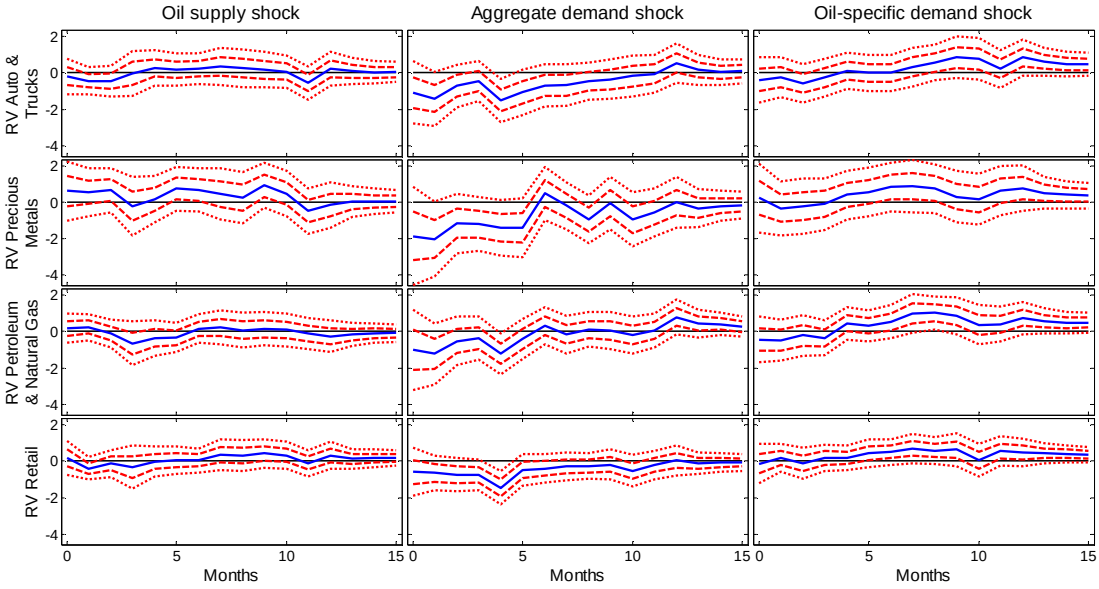
Figure 1. Responses of S&P500 volatility to structural oil shocks (Feb. 1975 - Dec. 2013)



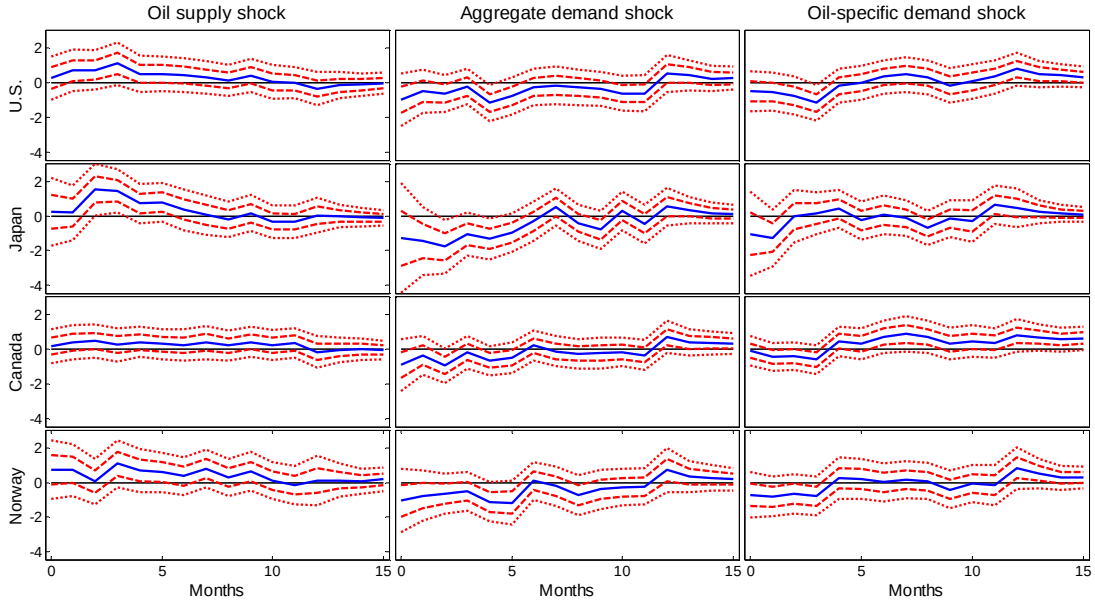
Notes: each panel shows the response of the annualized realized standard deviation of the S&P500 index to a one-standard deviation structural shock (continuous line), as well as one (dashed line) and two-standard error bands (dotted line). Estimates are based on bivariate VAR models of order 12 with one of the structural oil shocks ordered first and the volatility series ordered last. Confidence bands are based on a recursive-design wild bootstrap with 2000 replications (see Gonçalves and Kilian 2004).

Figure 2. Responses of industry portfolios volatility to structural oil shocks (Feb. 1975 - Dec. 2013)



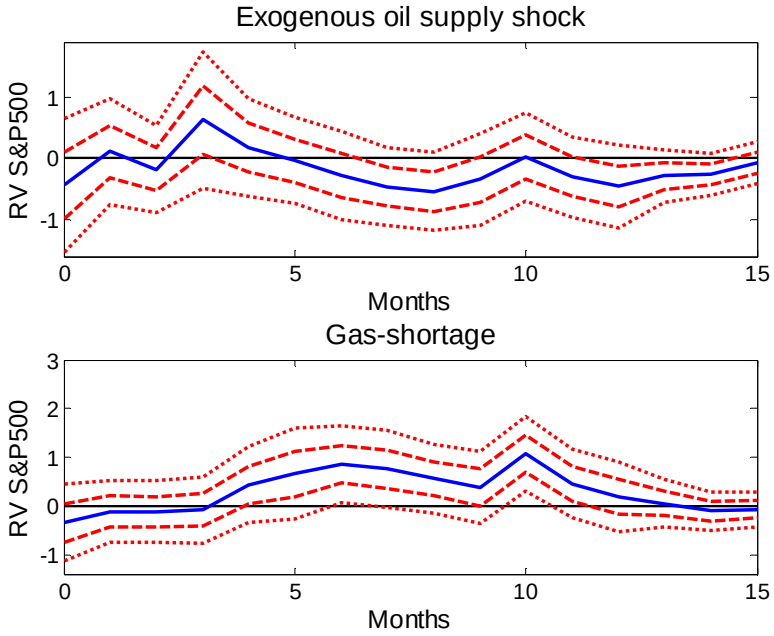
Notes: each row of the figure shows the response of the annualized realized standard deviation of the industry portfolio indicated on the label of the y-axis to a one-standard deviation structural shock (continuous line), as well as one (dashed line) and two-standard error bands (dotted line). Estimates are based on bivariate VAR models of order 12 with one of the structural oil shocks ordered first and the volatility series ordered last. Confidence bands are based on a recursive-design wild bootstrap with 2000 replications (see Gonçalves and Kilian 2004).

Figure 3. Responses of volatility to structural oil shocks by country (Jan. 1988 - Dec. 2013)



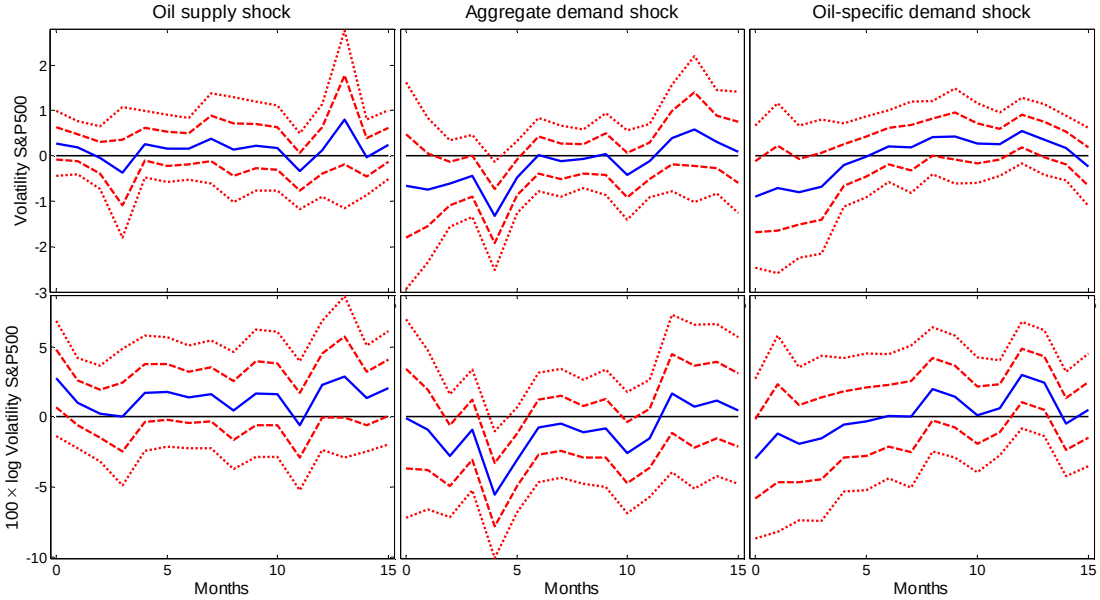
Notes: each row shows the response of the annualized realized standard deviation of the stock market index for the country indicated on the label of the y-axis to a one-standard deviation structural shock (continuous line), as well as one (dashed line) and two-standard error bands (dotted line). The stock market indices are the following: S&P500 (U.S.), Nikkei (Japan), S&P/TSX Composite (Canada) and Oslo Børs Benchmark (OSEBX; Norway). Estimates are based on bivariate VAR models of order 12 with one of the structural oil shocks ordered first and the volatility series ordered last. Confidence bands are based on a recursive-design wild bootstrap with 2000 replications (see Gonçalves and Kilian 2004).

Figure 4. Responses of S&P500 volatility to exogenous oil-supply shocks and gas-shortages (Feb. 1975 – Dec. 2013)



Notes: each panel shows the response of the annualized realized standard deviation of the S&P500 index to a one-standard deviation structural shock (continuous line), as well as one (dashed line) and two-standard error bands (dotted line). Estimates are based on bivariate VAR models of order 12 with one of the shocks ordered first and the volatility series ordered last. Confidence bands are based on a recursive-design wild bootstrap with 2000 replications (see Gonçalves and Kilian 2004). In the top panel the shock is measured as the exogenous oil supply proposed by Kilian (2008), while in the bottom panel the shock is measured by the (percent change of the) share of respondents to the University of Michigan Survey of Consumer Sentiment who quote gasoline shortages as a reason underlying poor conditions for buying a car.

Figure 5. Responses of S&P500 volatility to structural oil shocks from distributed lag models (Feb. 1975 - Dec. 2013)



Notes: each panel shows the response of the annualized realized standard deviation of the S&P500 index to a one-standard deviation structural shock (continuous line), as well as one (dashed line) and two-standard error bands (dotted line). Estimates are based on distributed lag models of order 15. The dependent variable is indicated on the label of the y-axis, while the regressors include a constant, the contemporaneous and lagged values of one of the structural oil shocks reported on the top of the panel. The responses are the estimates of the coefficients associated to the structural oil shocks, while confidence bands are based on 20000 block bootstrap replications with block size equal to 12 months.

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