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Explaining the Time-varying Effects Of Oil Market Shocks On U.S. Stock Returns*

Claudia Foroni[†] Pierre Guérin[‡] Massimiliano Marcellino[§]

February 20, 2017

Abstract

This paper documents time-variation in the relation between oil price and U.S. equity returns based on both reduced-form and structural analyses. Our reduced-form analysis suggests that a positive correlation between equity returns and oil price has emerged starting from the financial crisis. Based on our structural analysis, we find that oil-specific demand shocks have had positive effects on the U.S. stock market since 2008 as opposed to oil supply shocks, which have no large effects on stock returns. We also show that the time variation in the parameters of the structural VAR is very well explained by the level of the U.S. short-term interest rate and shifts in consumer confidence.

Keywords: Stock Returns, Oil Market Shocks, Time-varying Parameter VAR.

JEL Classification Code: G12, Q43, C32.

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1 Introduction

It has been argued that commodity-based assets could essentially serve as a hedge against stock market downturns in that the correlation between the U.S. stock market and the oil market was thought to be null. However, since the financial crisis of 2008-2009, the rising (and positive) correlation between oil price and stock returns has rekindled an interest in evaluating the reaction of U.S. stock returns to oil price fluctuations. The financial press has recently extensively commented on the fact that *"global financial markets are seemingly at the mercy of the oil price, with falls and rebounds in the commodity setting the tone for equity and other asset classes"* (Financial Times, 26 January 2016).

This topic has also attracted interest among academics and policy makers. A seminal contribution is Kilian and Park (2009), who show that the response of aggregate stock returns depends on the sources of the oil price shocks. In particular, they find that higher oil prices driven by unexpectedly strong global economic expansion have persistent positive effects on U.S. stock returns. Former Chairman of the Federal Reserve Bernanke also suggests that the positive oil-stock relation is mostly driven by changes in global demand, reiterating a point first made by Kilian and Park (2009).[1] It is also well documented that the relation between oil and equity returns has been unstable over time (see, e.g., Kilian and Park (2009) and recent evidence in Mohaddes and Pesaran (2016)).

In this paper, we first document changes in the correlation between the real price of oil and real stock returns over time. Kilian and Park (2009) show that this apparent time variation in the correlation between real oil returns and real equity returns can be explained by shifts in the composition of structural oil demand and oil supply shocks. We extend the structural model of Kilian and Park (2009) to allow for time variation in the coefficients of that model (and hence in the structural impulse responses), and we provide evidence of such time variation.[2] Further analysis shows that the time variation in the impulse responses appears to be correlated with variation in the U.S. short-term interest rate and with shifts in consumer sentiment.

The paper proceeds as follows. In Section 2, we provide a preliminary reduced-form evidence of time variation in the relationship between stock returns and oil price. In

[1]See the blog entry written by Ben Bernanke published on February 19, 2016 entitled "The relationship between stocks and oil prices," available at `https://www.brookings.edu/blog/ben-bernanke/2016/02/19/the-relationship-between-stocks-and-oil-prices/`

[2]Given the complexity of the model and the size of the sample, there is substantial uncertainty around the estimation, so that we cannot exclude that the data could be also approximated by a time-invariant model.

Section 3, we use a structural VAR model to study the effects of oil market shocks on U.S. real stock returns. In Section 4, we analyze whether the time variation we detect in the relationship between oil price shocks and stock returns can be explained by macroeconomic and financial variables. Section 5 concludes.

2 A preliminary look at the relation between stock returns and oil prices

As a first-pass evidence, we estimate a univariate time-varying parameter model of the monthly log change in real U.S. stock returns on the contemporaneous log change in the real price of oil (both oil and equity returns are deflated by the U.S. CPI from the Bureau of Labor Statistics). That is, we estimate the following regression

$$\Delta ln(sp_t) = \alpha_t + \beta_t \Delta ln(oil_t) + u_t exp(\frac{h_t}{2}) \qquad (1)$$

where α_t is a time-varying intercept, β_t captures the time varying relation between oil price and stock returns, and u_t is the error regression term following a standard normal distribution. We also include time-variation in the innovation of the model via a stochastic volatility process h_t. The price of oil is the West Texas Intermediate (WTI) and the stock returns series are obtained from the S&P 500 index returns. We model time variation in the parameters and latent variables α_t, β_t and h_t based on random-walk type behaviors.

The model is estimated with a standard Bayesian MCMC method and the sample extends from February 1973 to September 2015. Details on the estimation method are reported in the Online Appendix.

While the correlation between the real price of oil and real stock returns is not meaningfully different from zero for most of the sample (or even negative around specific events such as the 1990-1991 Gulf war), the correlation coefficient becomes positive at the start of the financial crisis. As such, this corroborates the evidence from Lombardi and Ravazzolo (2012) and Datta et al. (2016), who find that the correlation between stock market and oil price has increased markedly since 2008. To conserve space, we report in the Online Appendix the figure with the estimation results and additional comments.

One caveat of this reduced-form analysis is that it only captures (contemporaneous) correlation and thereby does not allow us to infer any causal relation from the oil market to the U.S. stock market. In the next section, we extend the linear VAR structural model of Kilian and Park (2009), introducing time-variation in all parameters of this model so as to be able to estimate the impact of oil market shocks on the U.S. stock market in a time-varying setting.

3 Has the relation between oil market shocks and the stock market changed over time?

In this section, we use a structural VAR model to study the effects of oil market shocks on U.S. real stock returns.[3] The (reduced-form) representation of the time-varying parameter VAR model with stochastic volatility is

$$z_t = A_{0,t} + \sum_{i=1}^{p} A_{i,t} z_{t-i} + e_t, \tag{2}$$

where e_t is a Gaussian white noise process with mean zero and covariance matrix Σ_t. Following Kilian and Park (2009), the vector z_t includes the following monthly variables: world oil production growth, the Kilian (2009) real economic activity index which is suitable for measuring economic activity in the context of the analysis of oil market, the real price of oil (in log-level) and real S&P500 returns (first difference of logs).

We use monthly data and the sample extends from February 1973 to September 2015. The training sample covers the first 25 monthly observations. The model is estimated with standard MCMC methods along the lines of Negro and Primiceri (2015).[4] We use a recursive identification scheme as in Kilian and Park (2009), ordering the variables as follows: first, world oil production growth, second, real economic activity index, third, the real price of oil, and fourth, U.S. real equity returns. Let e_t denote the reduced-form VAR innovations such that $e_t = B_t^{-1}\epsilon_t$. The structural innovations ϵ_t are derived by imposing exclusion restrictions on the B_t^{-1} matrix. In detail, we impose the following identifying

[3] An analysis on the oil market conducted with a time-varying VAR has been proposed by Kang et al. (2015). We depart from their study by investigating the potential drivers of time-variation.

[4] In particular, the posterior distribution of the states and hyperparameters are based on a burn-in period of 20,000 iterations to converge to the ergodic distribution, and we run 2000 further iterations retaining every second draw to reduce the autocorrelation across draws. The results presented in the paper are thereby based on 1000 draws from the posterior distribution. Recursive means vary little, suggesting evidence in favor of convergence. As an additional convergence check, note that sequential runs of the computer code led to virtually identical results.

assumptions:

$$e_t = \begin{pmatrix} e_{1t}^{\Delta\, global\, oil\, production} \\ e_{2t}^{global\, real\, activity} \\ e_{3t}^{real\, price\, of\, oil} \\ e_{4t}^{U.S.\, stock\, returns} \end{pmatrix} = \begin{bmatrix} b_{11,t} & 0 & 0 & 0 \\ b_{21,t} & b_{22,t} & 0 & 0 \\ b_{31,t} & b_{32,t} & b_{33,t} & 0 \\ b_{41,t} & b_{42,t} & b_{43,t} & b_{44,t} \end{bmatrix} \begin{pmatrix} \epsilon_{1t}^{oil\, supply\, shock} \\ \epsilon_{2t}^{aggregate\, demand\, shock} \\ \epsilon_{3t}^{oil-specific\, demand\, shock} \\ \epsilon_{4t}^{other\, shocks\, to\, U.S.\, stock\, returns} \end{pmatrix}. \quad (3)$$

Time variation in the autoregressive parameters is modelled via driftless random walk processes

$$\theta_t = \theta_{t-1} + \epsilon_t^{\theta}, \quad \epsilon_t^{\theta} \sim N(0, Q), \quad (4)$$

where $\theta_t = vec(A_t')$, $A_t = [A_{0,t}, ..., A_{p,t}]$, and $vec(.)$ is the column stacking operator.

The variance covariance matrix Σ_t is decomposed such that $\Sigma_t = B_t D_t B_t'$ where B_t is a lower triangular matrix and D_t a diagonal matrix with elements σ_i. Time variation for these parameters is obtained as follows

$$b_t = b_{t-1} + \epsilon_t^{b}, \quad \epsilon_t^{b} \sim N(0, V), \quad (5)$$

$$log(\sigma_{i,t}) = log(\sigma_{i,t-1}) + \epsilon_{i,t}^{\sigma}, \quad \epsilon_{i,t}^{\sigma} \sim N(0, R_i), \quad (6)$$

where $b_t = vec(B_t)$. The constant covariance matrices Q, V and R_i are independent and uncorrelated at all leads and lags. For additional details on the model specification and estimation method, we refer to the online appendix from Gali and Gambetti (2015).

A few additional comments are required. First, the lag length in the VAR is set to 6, which differs from the original lag length from Kilian and Park (2009), who worked with a VAR with 24 lags. Our modelling choice is driven by the computational challenges associated with the estimation of a time-varying parameter VAR with stochastic volatility with very long lag length.[5] Second, all three shocks we are interested in (oil supply, aggregate demand and oil-specific demand shocks) are scaled to represent a 1 per cent increase in the real price of oil. Using such a scaling of the shocks is in line with the oil market literature (see, e.g., Baumeister and Peersman (2013a)), given that, as pointed out by Baumeister and Peersman (2013b), the responses of the endogenous variables to one standard devi-

[5]As a word of caution on our modelling choice for the lag order in the VAR, Kilian (2009) shows the importance of including enough lags for precisely estimating the effects of global aggregate demand shocks. Using a low lag order can bias the results in favor of more explanatory power from the oil supply and oil-specific demand shocks. On the other hand, a long lag length can be also picking up parameter instability.

ation shocks would correspond to a different size of shock at each point in time, which complicates the comparison of the responses across the sample.[6]

Figure 1 shows the responses from the time-varying parameter model.[7] First, the time-varying parameter responses show that there is a substantial degree of time-variation in the responses in that an oil-specific demand shock associated with a 1 per cent increase in the real price of oil leads to a decline in U.S. real stock returns in the earlier part of the sample (up to the mid 1990's), but the same shock is instead associated with an increase in real stock returns in the recent past (starting from 2008). Second, the aggregate demand shock in global commodity markets (also scaled to match a 1 per cent increase in the real price of oil) has had increasingly positive effect on real stock returns with a maximum effect around the financial crisis, and effects that are generally much larger than those of oil-specific demand shocks.

Figure 2 reports the horizon-specific responses to all three structural oil market shocks along with posterior credible sets. Responses are plotted on impact and at a 4-month horizon.[8] A number of facts stands out: first, oil supply shocks do not have large effects on stock returns in that the responses do not differ from zero except for a brief period in the early 2000's. Second, the aggregate demand shock has had increasingly positive effect on stock returns until 2008, albeit the posterior credible sets exclude zero for only a short period in the run-up to the financial crisis of 2008-2009. Third, the sign of the response of oil-specific demand shocks has changed over time in that, since 2008, an increase in the real price of oil stemming from an oil-specific demand shock leads to an increase in stock returns whereas the stock returns response was negative in the 1990's. A potential explanation for this is the following. The shale oil revolution made the U.S. economy more sensitive to oil price fluctuations through changes in U.S. oil-related investment (see, e.g., Baumeister and Kilian (2016)). As a result, oil-specific demand shock associated with an increase in

[6]We acknowledge that normalizing the size of the shock is not innocuous. As explained in Baumeister and Peersman (2013b), in a time-varying model one cannot make the nature of a shock identical over time, so we decide to make the shock comparable only on the effect on the real oil price. Further, we follow the standard literature on time-varying VARs and condition on the history of the data to date, as we move through the sample, and compute the responses to the shocks (see, among others, Canova and Gambetti (2009)). This implies that the impulse responses of the endogenous variables at each point in time are conditional upon the history, which includes the effects of all previous shocks.

[7]We plot the median responses for the time-varying parameter model. This approach presents two shortcomings. The first is that the median response is unlikely to correspond to a single specific model, and the second is that the vector of medians is not the median of a vector valued random variable. See Kilian and Luetkepohl (2017) for additional details.

[8]We plot the impact responses as it is commonly done in the literature (see, e.g., Baumeister and Peersman (2013a)) and at a 4-month horizon to get a sense of the longer-run effects. At more distant projection horizons, posterior credible sets are very wide. As such, this suggests that one cannot exclude the fact that there is little time variation in the response of real stock returns to oil market shocks.

the price of oil (e.g., related to greater uncertainty about Middle Eastern oil supplies) is likely to boost U.S. oil-related investment, which is beneficial for the U.S. economy and by extension the U.S. stock market. A more comprehensive analysis of this issue is left for future research.

4 Explaining the time-variation in the relation between oil market shocks and the stock market

In this section, we explain the time-variation in the coefficients of the VAR system. In doing so, we summarize the time-series of all time-varying vector autoregressive coefficients by extracting the principal components. We then consider possible driving forces of the time variation and look at the explanatory power of the following macroeconomic variables: the National Financial Conditions Index (NFCI) of the Federal Reserve Bank of Chicago, measures of consumer expectations from the Michigan Consumer Survey as in Kilian and Vigfusson (2017), the effective federal funds rate (complemented by the Wu and Xia (2016) shadow interest rate over the zero lower bound period) as well as the VIX. We summarize here the main evidence. Results on the contemporaneous correlation coefficient and statistical significance are reported in the Online Appendix, together with the details on the extraction of the principal components and the estimation details.

We find that the level of the Federal funds rate looks relatively important in explaining the time-variation in the VAR coefficients. As such, this result lines up well with the finding in Datta et al. (2016), who suggest that the advent of the zero lower bound is a key determinant for the positive correlation between the price of oil and equity returns that emerged from 2008. Second, the NFCI has little-to-no explanatory power for the pattern of time variation in the coefficients of the VAR, suggesting that broad financial conditions are not an important determinant of the degree of time variation in the coefficients of the VAR (albeit the VIX has important explanatory power). Third, the principal components are also well-explained by consumer expectations of macroeconomic conditions related to business conditions and consumer sentiment. As such, our results are in line with the findings from Edelstein and Kilian (2009) who stress the importance of consumer confidence in the transmission of oil price shocks.

5 Conclusions

In this paper, we first document the emergence of a positive correlation between the real price of oil and U.S. real stock returns, starting from the 2008 financial crisis. Second, using a time-varying parameter structural VAR model, we find evidence in favor of substantial time-variation in the effects of oil market shocks on stock returns. In particular, oil-specific demand shocks have had positive effects on stock returns starting from 2008. Third, we find that the time-variation in the parameters of this structural VAR system is very well explained by the level of the federal funds rate, suggesting the important role played by the advent of the zero lower bound in explaining the positive relation between oil and equity returns that emerged from 2008.

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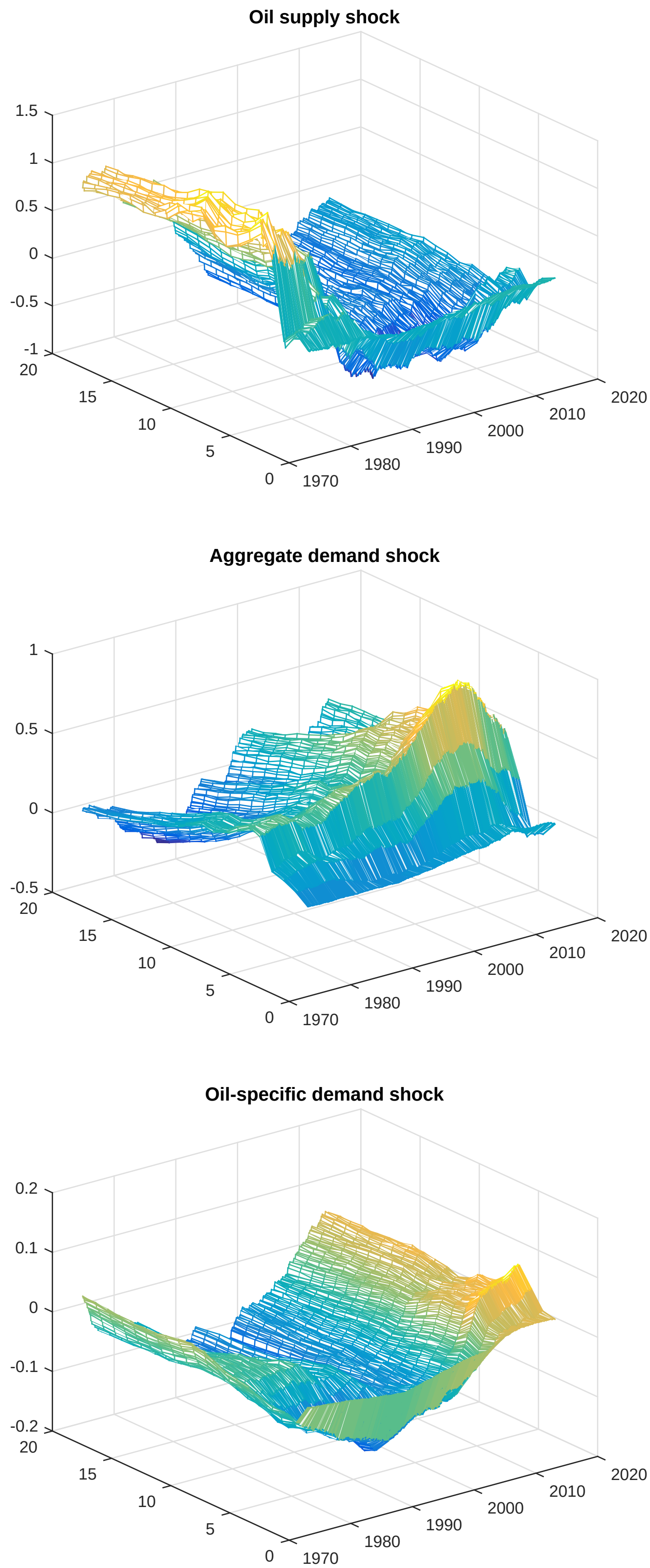
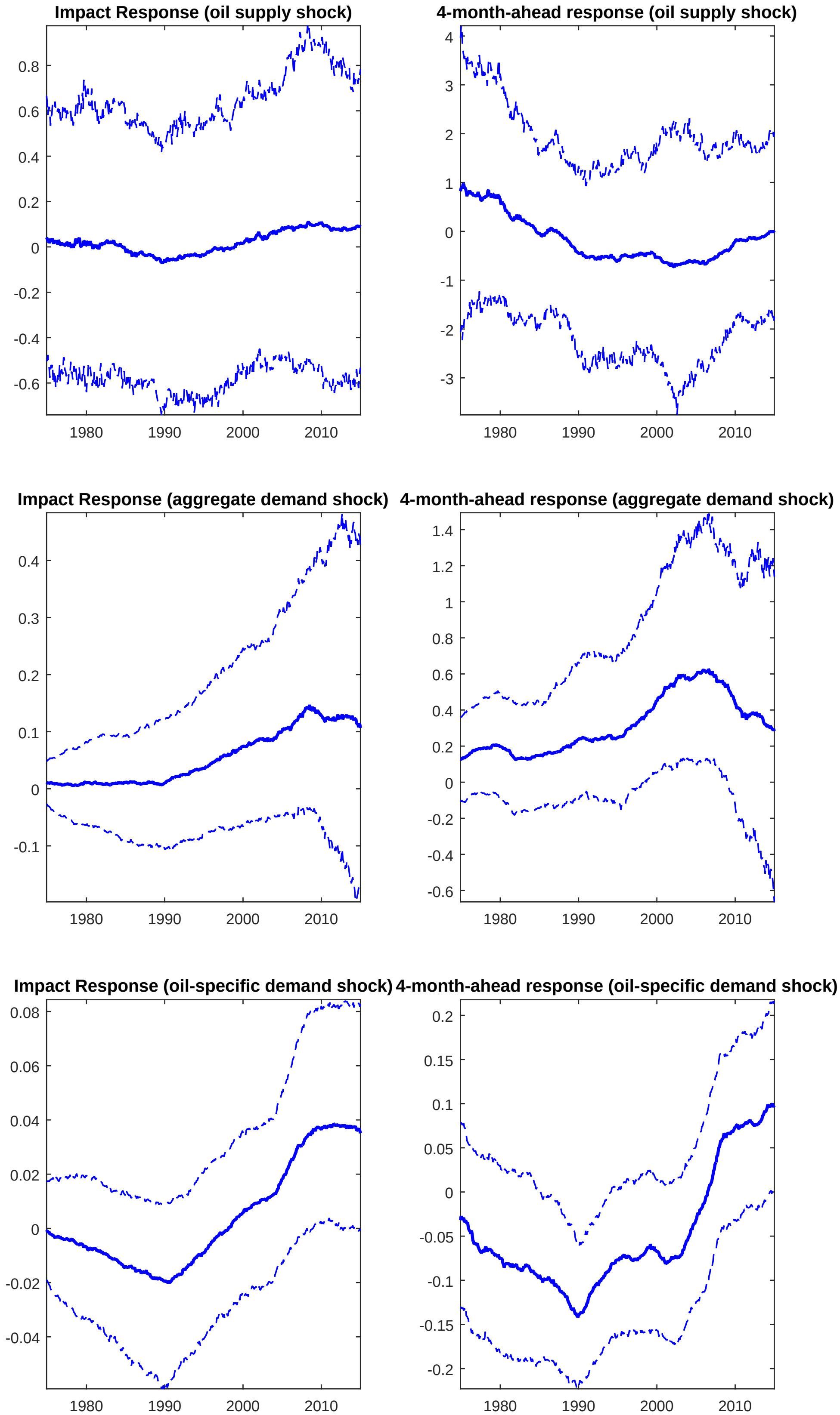
Figure 1: Responses of U.S. stock returns to oil market shocks (time-varying parameter VAR)



Note: This figure shows the time-varying cumulative median response of real stock returns (S&P500 index) to the three structural oil market shocks. All shocks are scaled to represent a 1 per cent increase in the real price of oil.

Figure 2: Horizon-specific responses of stock returns to oil market shocks



Note: Horizon specific impulse responses with 16^{th} and 84^{th} percentile confidence bands (same scaling of the shocks as in Figure 1).

Explaining the Time-varying Effects Of Oil Market Shocks On U.S. Stock Returns*

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Online Appendix

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A Correlation between real price of oil and real stock returns

We report the results of the time-varying parameter model of the monthly log change in real U.S. stock returns on the contemporaneous log change in the real price of oil (both oil and equity returns are deflated by the U.S. CPI from the Bureau of Labor Statistics), as described in Section 2 of the paper. That is, we estimate the following regression:

$$\Delta ln(sp_t) = \alpha_t + \beta_t \Delta ln(oil_t) + u_t exp(\frac{h_t}{2}) \tag{1}$$

where α_t is a time-varying intercept, β_t captures the time varying relation between oil price and stock returns, and u_t is the error regression term following a standard normal distribution. We also include time-variation in the innovation of the model via a stochastic volatility process h_t. The price of oil is the West Texas Intermediate (WTI) and the stock returns series are obtained from the S&P 500 index returns. We model time variation in the parameters and latent variables α_t, β_t and h_t based on random-walk type behaviors as it is commonly done in the literature, which implies relatively smooth changes in parameter estimates over time (as opposed to abrupt changes obtained via regime-switching parameters):

$$\alpha_t = \alpha_{t-1} + \epsilon_t^{\alpha}, \quad \epsilon_t^{\alpha} \sim N(0, \sigma^{\alpha}) \tag{2}$$

$$\beta_t = \beta_{t-1} + \epsilon_t^{\beta}, \quad \epsilon_t^{\beta} \sim N(0, \sigma^{\beta}) \tag{3}$$

$$h_t = h_{t-1} + \epsilon_t^{h}, \quad \epsilon_t^{h} \sim N(0, \sigma^{h}) \tag{4}$$

The model is estimated with a standard Bayesian MCMC method and the sample extends from February 1973 to September 2015. The model is estimated with a burn-in period of 20000 draws, running 2000 additional simulations. We keep every second draw of these additional simulations to reduce the autocorrelation across draws.

Figure 1 shows the results. First, as expected, the stochastic volatility estimates line up well with the episodes of substantial stress on financial markets in that volatility peaks in October 1987 and October 2008, and volatility is elevated at the time of the stock market decline following the burst of the dot com bubble in the early 2000s. Second, while the correlation between the real price of oil and real stock returns is not meaningfully different from zero for most of the sample (or even negative around specific events such as the 1990-1991 Gulf war), the correlation coefficient becomes positive at the start of the financial crisis.

B Explaining the time-variation in the relation between oil market shocks and the stock market

In section 4 of the paper, we explain the time-variation in the coefficients of the VAR system. We first extract the principal components from the time-series of all time-varying vector autoregressive coefficients (i.e., 100 time-varying parameters corresponding to a 4-equation VAR with six autoregressive lags).[1] In doing so, we use the median estimates of the posterior distribution of the coefficients, and use the (standardized) first difference of the coefficients to ensure stationary before performing principal component analysis. We consider the explanatory variables used in Kilian and Vigfusson (2017). The NFCI is taken directly from the Federal Reserve Bank of Chicago webpage, while the measures of consumer expectations are taken from the Michigan Consumer Survey. Further, we consider the effective federal funds rate (complemented by the Wu and Xia (2016) shadow interest rate over the zero lower bound period) as well as the VIX. In Tables 1 to 3, we report the contemporaneous correlation coefficient (and statistical significance) obtained by an OLS regression of the k^{th} principal component on a specific macroeconomic variable, and we also report the R^2 of the regression.

First, it is interesting to note that the first three principal components together explain roughly 34% of the total variance.[2] Second, the first and third principal components are rather well explained by the level of the Federal funds rate. As such, this result lines up well with the finding in Datta et al. (2016), who suggest that the advent of the zero lower bound is a key determinant for the positive correlation between the price of oil and equity returns that emerged from 2008. Second, the NFCI has little-to-no explanatory power for the pattern of time variation in the coefficients of the VAR, suggesting that broad financial conditions are not an important determinant of the degree of time variation in the coefficients of the VAR (albeit the VIX has important explanatory power for the third principal component). Third, the first and second principal components are also well-explained by consumer expectations of macroeconomic conditions related to business conditions and consumer sentiment. Moreover, the variables “Buying Conditions for Vehicles” and “Expected Change in Financial Situation Next Year” also explain well the second principal component. As such, our results are in line with the findings from Edelstein and Kilian (2009) who stress the importance of consumer confidence in the transmission of oil price shocks.

[1] Similar results are obtained when we run the same analysis, but with the principal components extracted only from the coefficients of the stock return equation. Results are available upon request.

[2] In detail, the first, second and third principal components explain 16.7 percent, 9.5 percent and 7.4 percent of the total variance, respectively.

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Table 1: First principal component

	Correlation	P-value	R-squared
NFCI (adj)	-0.034	0.012	0.014
Umich: Consumer Sentiment	-0.006	0.000	0.113
Buying Conditions for Homes (rel)	0.002	0.000	0.041
Buying Conditions for Large Households Items (rel)	-0.002	0.000	0.028
Buying Conditions for Vehicles (rel)	0.000	0.463	0.001
Expected Change in Unemployment Next Year (rel)	0.000	0.804	0.000
Expected Change in Business Conditions Next Year (rel)	-0.003	0.000	0.111
Expected Change in Interest Rate Next Year (rel)	-0.001	0.005	0.017
Expected Change in Financial Situation Next Year (rel)	-0.007	0.000	0.101
VIX	-0.008	0.000	0.058
Federal funds rate	-0.026	0.000	0.218

Note: This table shows the contemporaneous correlation between the first principal component of the time-varying coefficients of the VAR with macroeconomic conditions. The R-squared is based on a regression of the first principal component on an intercept and the contemporaneous value of the explanatory variable. All regression sample sizes extend from February 1978 to September 2015 (except for the VIX for which the start date of the sample is January 1990).

Table 2: Second principal component

	Correlation	P-value	R-squared
NFCI (adj)	-0.028	0.006	0.017
Umich: Consumer Sentiment	0.006	0.000	0.175
Buying Conditions for Homes (rel)	0.002	0.000	0.117
Buying Conditions for Large Households Items (rel)	0.004	0.000	0.164
Buying Conditions for Vehicles (rel)	0.005	0.000	0.217
Expected Change in Unemployment Next Year (rel)	0.000	0.745	0.000
Expected Change in Business Conditions Next Year (rel)	0.002	0.000	0.085
Expected Change in Interest Rate Next Year (rel)	-0.001	0.001	0.024
Expected Change in Financial Situation Next Year (rel)	0.009	0.000	0.249
VIX	0.001	0.521	0.001
Federal funds rate	-0.007	0.001	0.026

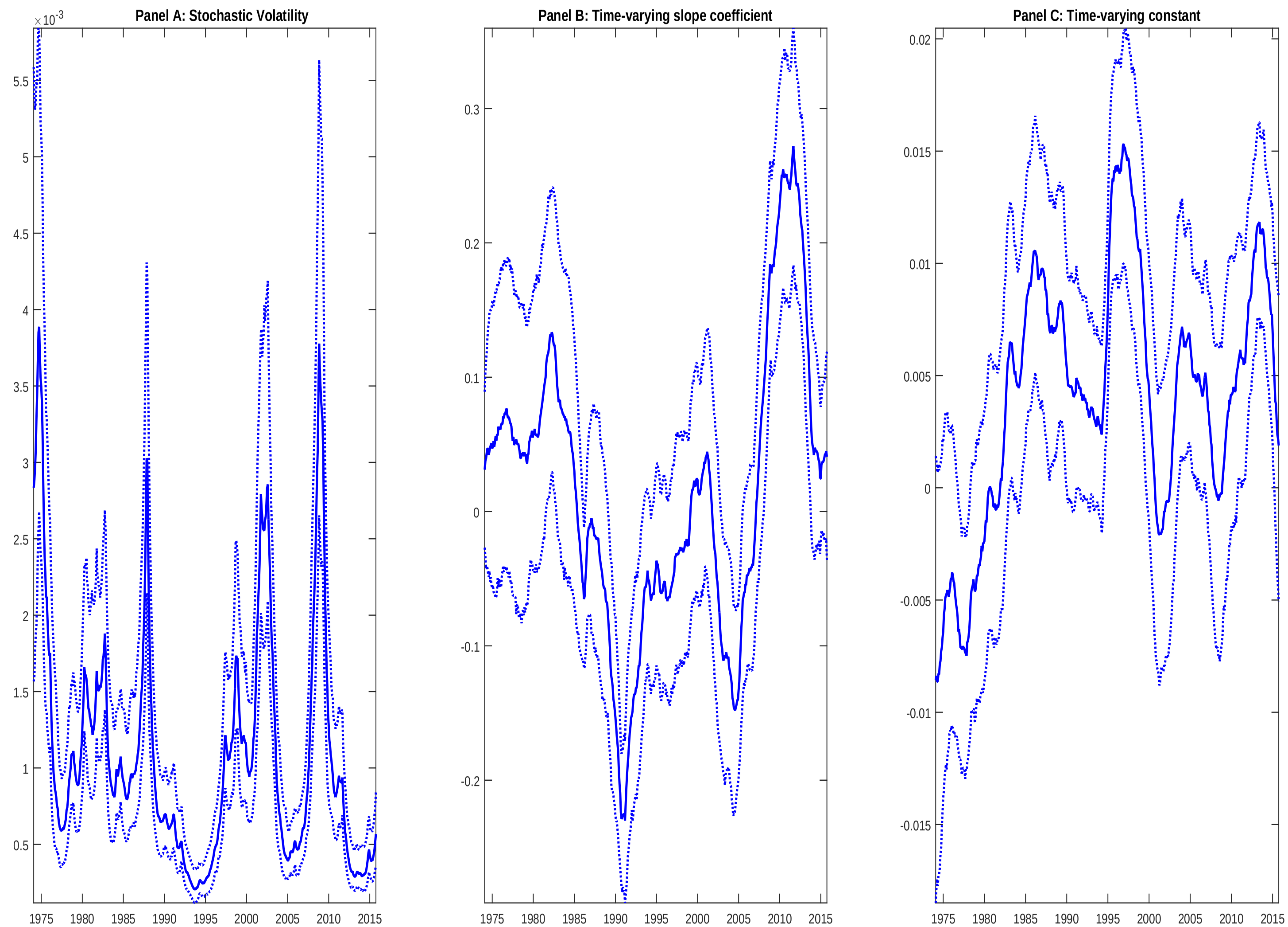
Note: See note to Table 1.

Table 3: Third principal component

	Correlation	P-value	R-squared
NFCI (adj)	-0.025	0.011	0.014
Umich: Consumer Sentiment	-0.001	0.078	0.007
Buying Conditions for Homes (rel)	-0.002	0.000	0.134
Buying Conditions for Large Households Items (rel)	-0.001	0.183	0.004
Buying Conditions for Vehicles (rel)	-0.002	0.000	0.049
Expected Change in Unemployment Next Year (rel)	-0.002	0.000	0.038
Expected Change in Business Conditions Next Year (rel)	-0.001	0.006	0.017
Expected Change in Interest Rate Next Year (rel)	0.000	0.531	0.001
Expected Change in Financial Situation Next Year (rel)	0.000	0.872	0.000
VIX	-0.009	0.000	0.141
Federal funds rate	0.014	0.000	0.125

Note: See note to Table 1.

Figure 1: Time-varying parameter model with stochastic volatility



Note: This figure shows the results from the estimation of the model described by equations (1) to (4). Panel A shows the stochastic volatility estimates, Panel B shows the time-varying slope coefficient and Panel C represents the time-varying constant.