Oil Price Shocks in Major Emerging Economies*

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Abstract:

As the world economic power shifts from the advanced G7 countries — Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States — to the seven largest emerging market countries (EM7) — Brazil, China, India, Indonesia, Mexico, Russia, and Turkey — the vulnerability of these emerging market countries to exogenous shocks is becoming of growing importance. This paper presents a comprehensive examination of the effects of oil price shocks on real economic activity in the EM7 economies in the context of two classes of empirical models. In general, we find that oil price uncertainty has statistically significant effects on the real output of the EM7 economies and that the relationship between oil prices and economic activity is in general symmetric. We also find that oil price uncertainty has in general a negative effect on world crude oil production.

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1 Introduction

The seven largest emerging market economies (henceforth EM7) — Brazil, China, India, Indonesia, Mexico, Russia, and Turkey — could be double the size of their advanced counterparts, the G7 — Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States — by 2040, according to the estimates by Hawksworth *et al.* (2017). This is a massive shift in world economic power from advanced economies to emerging market economies, especially striking since two decades ago these economies were half the size of their advanced counterparts. Hawksworth *et al.* (2017) also estimates that by the year 2050, the EM7 economies could increase their share of world gross domestic product to 50% from approximately 35% today. In fact, based on GDP at purchasing power parity, China could be the largest economy in the world, followed by India and Indonesia in fourth place. The EM7 economies will be the primary drivers of world economic growth, growing at an estimated average rate of 3.5% per annum for every year up to 2050, dwarfing the 1.6% annual growth rate of the advanced G7 countries. See Hawksworth *et al.* (2017) for more details.

With the shift in global economic power to emerging market economies, it is important to examine the vulnerability of these economies to shocks that might have adverse effects on real economic activity in these economies. There is a vast empirical literature that investigates whether positive shocks in the price of oil lead to recessions in advanced countries like the United States — see, for example, Edelstein and Kilian (2009), Elder and Serletis (2010), and Kilian and Vigfusson (2011). Bredin *et al.* (2011) report that among the G7, uncertainty about oil prices has had an adverse effect on manufacturing activity in Canada, France, the United Kingdom, and the United States. Investigation of similar shocks to members of the EM7 countries has been an area in the empirical literature that has been relatively understudied.

This paper contributes to the empirical literature through its investigation of how oil price shock affect economic activity in the EM7 countries, of whether oil price uncertainty affects real economic activity in the EM7, and whether the relationship between oil prices and the level of economic activity in the EM7 countries is asymmetric. In doing so, we use two classes of empirical models. In particular, we extend the Elder and Serletis (2010) model, incorporating aspects of the Kilian (2009) and Kilian and Park (2009) methodology, to investigate the effects of oil price uncertainty. We also use the Kilian and Vigfusson (2011) methodology to test for symmetry in the impulse responses of real output to positive and negative oil price shocks in the EM7 countries.

In the context of a multivariate GARCH-in-Mean VAR specification, that controls for lagged changes in global crude oil production and world economic activity, we find that oil price uncertainty has a negative and statistically significant effect on real output in India, Indonesia, Mexico, Russia, and Turkey, and a positive and statistically significant effect on real output in Brazil and China. We also find that the responses of real economic activity to oil price shocks in China, India, Indonesia, Mexico, and Turkey are symmetric and those in Brazil and Russia are asymmetric.

The remainder of the paper is organized as follows. In Section 2, we discuss the multivariate GARCH-in-Mean VAR model, incorporating demand and supply side shocks in the world crude oil market, as in Kilian (2009) and Kilian and Park (2009). In Section 3, we discuss the data and their time series properties, and in Section 4 present the empirical results regarding the effects of oil price uncertainty. In section 5, we investigate whether the relationship between real economic activity and the real oil price is nonlinear and asymmetric and in doing so we use the Kilian and Vigfusson (2011) tests of the null hypothesis of symmetric impulse responses. The final section concludes the paper.

2 The Multivariate GARCH-in-Mean VAR

Elder and Serletis (2010) use the Elder (2004) model and investigate the relationship between the price of oil and the level of economic activity, focusing on the role of uncertainty about oil prices. In doing so, they utilize an internally consistent bivariate GARCH-in-Mean structural VAR that accommodates an independent role for the effects of oil price volatility. They find that volatility in oil prices has had a negative and statistically significant effect on several measures of investment, durables consumption, and aggregate output. They also find that accounting for the effects of oil price volatility tends to exacerbate the negative dynamic response of economic activity to a negative oil price shock, while dampening the response to a positive oil price shock.

In this section, we follow Elder and Serletis (2010) and consider an extension of their bivariate structural GARCH-in-Mean VAR model to investigate the relationship between oil price uncertainty and real output, after controlling for global crude oil production and world economic activity, building on the work by Kilian (2009) and Kilian and Park (2009). Existing studies that analyze the relationship between the price of oil and real output in the context of bivariate models suffer from the limitation that oil prices are assumed to be strictly exogenous with respect to the global economy. In this regard, Kilian (2009) provides empirical evidence that fluctuations in global macroeconomic activity have an impact on the price of oil. Therefore, in what follows, we investigate the relationship between oil prices and domestic real output, after we control for economic variables that drive both the price of oil as well as domestic real output.

We assume that the dynamics of the structural system can be summarized by a linear function of the relevant vector of macroeconomic variables, modified to allow the conditional volatility of the real price of oil to affect the conditional mean

$$\boldsymbol{B}\boldsymbol{z}_t = \boldsymbol{C} + \boldsymbol{\Gamma}_1\boldsymbol{z}_{t-1} + \boldsymbol{\Gamma}_2\boldsymbol{z}_{t-2} + ... + \boldsymbol{\Gamma}_p\boldsymbol{z}_{t-p} + \boldsymbol{\Lambda}\sqrt{\boldsymbol{h}_t} + \boldsymbol{\epsilon}_t \tag{1}$$

where $\boldsymbol{z}$ is a column vector in the percentage change in global crude oil production, $\Delta \ln prod_t$, world economic activity, wea_t, percentage change in real price of oil, $\Delta \ln o_t$, and the growth rates of real output in each of the EM7 countries, $\Delta \ln y_t$. In equation (1), $\dim(\boldsymbol{B}) = \dim(\boldsymbol{\Gamma}_j)$ $= (4 \times 4)$ and $\boldsymbol{\epsilon}_t \,|\Omega_{t-1} \sim$i.i.d. N($\mathbf{0}$, $\boldsymbol{H}_t$), with $\boldsymbol{H}_t$ being the variance-covariance matrix. Also,

$$\boldsymbol{B} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & b_{34} \\ b_{41} & b_{42} & b_{43} & b_{44} \end{bmatrix}; \quad \boldsymbol{\Gamma}_j = \begin{bmatrix} \gamma_{11}^j & \gamma_{12}^j & \gamma_{13}^j & \gamma_{14}^j \\ \gamma_{21}^j & \gamma_{22}^j & \gamma_{23}^j & \gamma_{24}^j \\ \gamma_{31}^j & \gamma_{32}^j & \gamma_{33}^j & \gamma_{34}^j \\ \gamma_{41}^j & \gamma_{42}^j & \gamma_{43}^j & \gamma_{44}^j \end{bmatrix}; \quad \boldsymbol{\epsilon}_t = \begin{bmatrix} \epsilon_{\Delta \ln prod_t} \\ \epsilon_{wea_t} \\ \epsilon_{\Delta \ln o_t} \\ \epsilon_{\Delta \ln y_t} \end{bmatrix};$$

$$\boldsymbol{H}_t = \begin{bmatrix} h_{\Delta \ln prod_t} & 0 & 0 & 0 \\ 0 & h_{wea_t} & 0 & 0 \\ 0 & 0 & h_{\Delta \ln o_t} & 0 \\ 0 & 0 & 0 & h_{\Delta \ln y_t} \end{bmatrix}; \quad \boldsymbol{h}_t = \begin{bmatrix} h_{\Delta \ln prod_t} \\ h_{wea_t} \\ h_{\Delta \ln o_t} \\ h_{\Delta \ln y_t} \end{bmatrix}; \quad \boldsymbol{\Lambda} = \begin{bmatrix} 0 & 0 & \lambda_{13} & 0 \\ 0 & 0 & \lambda_{23} & 0 \\ 0 & 0 & \lambda_{33} & 0 \\ 0 & 0 & \lambda_{43} & 0 \end{bmatrix}.$$

The model is identified by imposing a sufficient number of exclusion restrictions on the $\boldsymbol{B}$ matrix. In this four variable structural VAR case, we estimate $n(n-1)/2 = 6$ free parameters in $\boldsymbol{B}$, subject to a rank condition, such that the diagonal elements of $\boldsymbol{B}$ are assumed to be equal to 1 and $\boldsymbol{B}$ is assumed to be lower triangular. The block-recursive structure of $\boldsymbol{B}$ implies that world crude oil production, world real economic activity, and the real price of oil are predetermined with respect to domestic real output. Global oil production is assumed to be exogenous to the other three variables (it is affected only by a shock to itself but is unaffected by instantaneous feedback from the other variables). Thus, our recursive factorization structure imposes six exclusion restrictions on the $\boldsymbol{B}$ matrix, satisfying a rank condition. The restrictions on the $\boldsymbol{B}$ matrix allow us to differentiate between three structural shocks that affect the real price of oil, namely unanticipated changes in world oil production that are referred to as supply shocks, contemporaneous changes in the demand for oil generated from structural innovations in world economic activity, referred to as aggregate demand shocks, and shocks that are unique to the demand for oil, referred to as oil-specific demand shocks.

Finally, we allow the conditional variance matrix, $\boldsymbol{H}_t$, to follow a multivariate GARCH process as follows

$$\begin{bmatrix} h_{\Delta \ln prod_t} \\ h_{wea_t} \\ h_{\Delta \ln o_t} \\ h_{\Delta \ln y_t} \end{bmatrix} = \begin{pmatrix} C_1 + F_1 \epsilon^2_{\Delta \ln prod_{t-1}} + G_1 H_{\Delta \ln prod_{t-1}} \\ C_2 + F_2 \epsilon^2_{wea_{t-1}} + G_2 H_{wea_{t-1}} \\ C_3 + F_3 \epsilon^2_{\Delta \ln o_{t-1}} + G_3 H_{\Delta \ln o_{t-1}} \\ C_4 + F_4 \epsilon^2_{\Delta \ln y_{t-1}} + G_4 H_{\Delta \ln y_{t-1}} \end{pmatrix} \tag{2}$$

The multivariate GARCH-in-Mean VAR model, consisting of equations (1) and (2), is estimated using full information maximum likelihood — see Elder and Serletis (2010) for more details. We used the RATS (version 9) software and initially attempted to estimate the model with one full year of lags, but had convergence problems in the large parameters space. To deal with this, we used the AIC criterion to optimally select the lag length.

3 The Data

We use industrial production data for the seven emerging economies from three different sources. For Brazil, India, Mexico, Russia, and Turkey, we use total industrial production data from the Organization for Economic Cooperation and Development (OECD) Main Economic Indicators: Production and sales database. Due to the lack of comprehensive monthly industrial production data for China, we use the monthly real GDP series constructed (and used) by Higgins *et al.* (2016) as a proxy for industrial production. Finally, for Indonesia, we retrieve the Industrial/Manufacturing Production growth rate from the Asia Regional Integration Center: Economic and Financial Indicators Database of the Asian Development Bank.

In our structural VAR analyses, we use the real price of oil as in Barsky and Kilian (2001), Kilian (2009), Kilian and Park (2009), Elder and Serletis (2010), and Jo (2014). We retrieve data for the variable Crude Oil (petroleum), Dated Brent, light blend 38 API, fob U.K. from the International Monetary Fund's primary commodity prices data set. The original data is in US dollars per barrel. To obtain the real price of oil in domestic currency, we first multiply the series with the exchange rate (local currency per US dollar) and then deflate the nominal data by the domestic Consumer Price Index (CPI) for all items. The data for the exchange rate and the domestic consumer price index has been retrieved from FRED. The data sources are comprehensively described in Appendix Table A1. It is to be noted that the sample period varies from country to country due to the difference in the availability of comprehensive data for industrial production, CPI, and the exchange rate for each country. The Brent oil price data starts in 1980. For Brazil, even though the OECD industrial production data starts in 1975, we are restricted to start from 1980. All the data was downloaded on 3 April 2019.

In Figure 1 we plot the natural logarithm of industrial production and the corresponding growth rate for Brazil, China, India, Mexico, Russia, and Turkey, as well as the growth rate of Indonesia's industrial production. In Figure 2, we plot the logged real oil price (in terms of domestic currency) and its associated growth rate for each of the EM7 countries. We also use data for world oil production from the U.S. Energy Information Administration. For the world economic activity series, we use the (updated and corrected version of the) index of global real economic activity in industrial commodity markets proposed by Kilian (2009) and downloaded from Kilian's website. In Figure 3 we plot the natural log of the world crude oil production series and its corresponding growth rate and in Figure 4 the world economic activity series.[1]

We conduct a series of unit root tests in the growth rates of industrial production and the real oil price. We calculate the growth rate by taking the logarithmic first difference of the

[1] In this model, and for purposes of achieving convergence, we use the world economic activity series multiplied by 12/100.

original series and multiplying by 100, except for Indonesia. For Indonesia, the original series requires no transformation, since the original data represents the Industrial/Manufacturing Production growth rate. The data transformations are shown in Appendix Table A2. Specifically, we carry out three tests to test for the presence of unit roots in our time series, namely the Augmented Dickey-Fuller (ADF) test [see Dickey and Fuller (1981)], the Phillips-Perron unit root test [see Phillips and Perron (1988)], and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test [see Kwiatkowski *et al.* (1992)]. We assume a constant and a trend for all three unit root tests. The null hypothesis for the ADF and PP tests is that a unit root is present in a time series sample, while the null hypothesis for the KPSS test is that the data is stationary.

We report the p-values for the ADF and PP tests and the KPSS test statistics in Table 1 (in panel A for the growth rate of industrial production and in panel B for the growth rate of the real oil price). As can be seen, the null hypothesis of the presence of unit root is rejected at the 1% significance level by both the ADF and PP tests, while the null hypothesis of stationarity cannot be rejected at the 1% significance level by the KPSS test. We conclude that the industrial production and real oil price growth rates of the EM7 countries are all stationary. In panel C of Table 1, we also carry out the unit root and stationarity tests on the growth rate of world oil production, $\Delta \ln prod_t$, and on the series of world economic activity. Kilian and Zhou (2018) state that the global real activity index is "constructed as a business cycle index and, hence, must not be differenced or otherwise transformed." The p-values for the ADF tests are 0.000 for $\Delta \ln prod_t$ and 0.003 for the global economic activity series. The p-values for the PP tests are 0.000 for $\Delta \ln prod_t$ and 0.015 for the global economic activity series. Thus, the null hypothesis of a unit root is rejected at conventional significance levels by both the ADF and PP tests. The KPSS test statistics are 0.040 for $\Delta \ln prod_t$ and 0.132 for the global economic activity series, suggesting that the null hypothesis of stationarity cannot be rejected at the 1% significance level.

4 Empirical Evidence

We start be reporting in Table 2 the SIC values for a conditional homoscedastic VAR and our multivariate GARCH-in-Mean VAR. As can be seen in the table, the multivariate GARCH-in-Mean VAR captures more important features of the data than its homoscedastic counterpart, with the SIC values being considerably lower than that for the conventional homoscedastic VAR.

In the third column of Table 3, we report the maximum likelihood estimates of the primary coefficient of interest, $\hat{\lambda}_{43}$, with p-values in parenthesis, for each of the EM7 countries. $\hat{\lambda}_{43}$ gives the effect of uncertainty in the real oil price on domestic real output, after accounting for the supply side and demand side shocks to the real oil price. As can be seen, the coefficient of interest, $\hat{\lambda}_{43}$, is 0.021 with p-value of 0.021 for Brazil, 0.013 with a p-value of

0.072 for China, -0.070 with a p-value of 0.000 for India, -0.030 with a p-value of 0.000 for Indonesia, -0.065 with p-value of 0.000 for Mexico, -0.040 with a p-value of 0.054 for Russia, and -0.046 with a p-value of 0.000 for Turkey. More specifically, oil price uncertainty has a negative effect on real output in India, Indonesia, Mexico, Russia, and Turkey, and a positive and statistically significant effect on real output in Brazil and China.

In the fourth column of Table 3, we also report the estimates of the λ_{13} coefficient (with p-values in parentheses) for each of the EM7 countries; $\hat{\lambda}_{13}$ gives the effect of real oil price uncertainty on world oil production. Looking at the point estimates and their corresponding p-values, we see that oil price uncertainty has a negative and statistically significant effect on world crude oil production in six emerging market countries, namely Brazil, China, India, Indonesia, Mexico, and Turkey, and a negative and statistically insignificant effect on world crude oil production in Russia. Thus, we can also conclude that oil price uncertainty has in general an adverse effect on world crude oil production.

It is to be kept in mind that we should be cautious in interpreting results for China, since our time series is monthly interpolated real GDP growth data from quarterly frequency. Interpolated data has been criticized in the literature for giving spurious regression results — see Kilian (2009). Chinese data has also been criticized heavily in the literature for intentional falsification and overstatement. In this regard, Zheng (2001, p. 336) states that "there is serious weakness in some fields of national accounts such as transportation, real estate, education, and science and technology; in the price system underpinning the national accounts; and in the breakdown of the GDP accounts into components (e.g.,consumption and other segments of aggregate expenditure). China has barely begun to work on methods of incorporating environmental issues into the system of national accounts. The quarterly GDP estimates are crudely calculated with heavy reliance on estimates and excessive aggregation." Finally, Rawski (2001, p. 347) argues that official statistics of Chinese real output growth beginning in 1998 are subject to major exaggerations. They claim that "the standard data contain numerous inconsistencies. Chinese commentaries castigate widespread falsification at lower levels and question the authenticity of figures emanating from the central statistical authorities. The author speculates that cumulative GDP growth during 1997/2001 was no more than one-third of official claims, and possibly much smaller." More recently, Chen *et al.* (2019) estimate that official growth in China's GDP was overstated by 1.7 percentage points in the period from 2008 to 2016 and the investment and savings rates in 2016 were overstated by 7 percentage points.

In this regard, panel (b) of Figure 1 may provide some hints regarding this issue. In particular, output in China has grown steadily over the sample period, with little variation that might be expected to be associated with cyclical expansions and contractions. We are therefore not surprised that oil price uncertainty does not have a negative effect on Chinese output growth. As for Brazil, the puzzling result might be due to the fact that Brazil is a large methanol producer and the methanol output can be influenced by the crude oil price. In fact, Brazil is the second largest producer of ethanol in the world after the

United States. As of 2017, the U.S. and Brazil produce 85% of the world's ethanol (see https://afdc.energy.gov). A hike in the price of the substitute, crude oil, would increase the demand for ethanol. According to Hira and de Oliveira (2009, p. 2450), "Brazil has been able to substitute petroleum for ethanol for 20% of automotive fuel and 80% of Brazilian cars can take various blends of gas and ethanol."

5 On the (A)symmetric Relationship

Over the years, it has been argued that the relationship between oil prices and real economic activity is asymmetric, with the correlation between oil price increases and real output significantly different than the correlation between oil price decreases and real output — see, for example, Mork (1989) and Hamilton (2003). This is consistent with our evidence in the previous section that oil price uncertainty has a significant effect on all seven countries. More recently, Kilian and Vigfusson (2011) develop a formal statistical test of the null hypothesis of symmetric impulse responses to positive and negative oil price shocks, based on impulse response functions. As Kilian and Vigfusson (2011, p. 436) put it, "what is at issue in conducting this impulse-response-based test is not the existence of asymmetries in the reduced form parameters, but the question of whether possible asymmetries in the reduced form imply significant asymmetries in the impulse response function."

In this section, we use the Kilian and Vigfusson (2011) symmetry test to check for symmetry in the responses of real output to positive and negative oil price shocks. The test is carried out by estimating the following non-linear structural model

$$\Delta \ln o_t = \alpha_{10} + \sum_{j=1}^{p} \beta_{11}(j) \Delta \ln o_{t-j} + \sum_{j=1}^{p} \beta_{12}(j) \Delta \ln y_{t-j} + u_{1t}$$

$$\Delta \ln y_t = \alpha_{20} + \sum_{j=0}^{p} \beta_{21}(j) \Delta \ln o_{t-j} + \sum_{j=1}^{p} \beta_{22}(j) \Delta \ln y_{t-j} + \sum_{j=0}^{p} \delta_{21}(j) \tilde{o}_{t-j} + u_{2t}$$

where $\tilde{o}_t$ is a non-linear function of the growth rate of the real oil price

$$\tilde{o}_t = \max\left[0, \ln o_t - \max\left\{\ln o_{t-1}, \ln o_{t-2}, \ln o_{t-3}, \cdots, \ln o_{t-12}\right\}\right].$$

The null hypothesis of symmetric impulse responses of $\Delta \ln y_t$ to positive and negative real oil price growth rate shocks of the same size is

$$H_0 : I_y(h, \delta) = -I_y(h, -\delta) \quad \text{for } h = 0, 1, ..., H$$

and tests whether the response of $\Delta \ln y_t$ to a positive shock in the oil price growth rate of size δ is equal to the negative of the response of y_t to a negative shock in the oil price growth rate of the same size, $-\delta$, for horizons $h = 0, 1, ..., H$. For a detailed discussion of the methodology, see Kilian and Vigfusson (2011).

In Table 4, we report p-values of the null hypothesis and since the test depends on the size of the shock, we report results for both small shocks (one standard deviation shocks, $\delta = \hat{\sigma}$) and large shocks (two standard deviation shocks, $\delta = 2\hat{\sigma}$). The test is conducted for 12 months, based on 10,000 simulations and 50 histories. As can be seen in Table 4, in general the null hypothesis of a symmetric relationship between the growth rates of the real oil price and real output cannot be rejected at conventional significance levels for China, India, Indonesia, Mexico, and Turkey. The null hypothesis, however, is rejected for Brazil and Russia.

In the previous section, we found that oil price uncertainty has a negative and statistically significant effect on real output in India, Indonesia, Mexico, Russia, and Turkey, and a positive and statistically significant effect on real output in Brazil and China, implying that the impulse-responses are asymmetric for all these countries. However, the Kilian and Vigfusson (2011) test for symmetry rejects the null of symmetry only Brazil and Russia. This could be because the Kilian and Vigfusson (2011) test is a generalized test for symmetry and will have lower power against any specific alternative. It could be that the failure to reject symmetry for China, India, Indonesia, Mexico, and Turkey could simply be due to low power with respect to this particular alternative. In this regard, as Jo (2014, p. 1114) put it, "the consensus in the literature is that there is no compelling evidence of asymmetric responses at the aggregate level in the U.S. or in other industrialized economies, whereas the evidence at the disaggregate level is mixed. While there is evidence of an uncertainty effect for oil producers in Texas, as shown by Kellogg (2010), tests for asymmetric responses of industrial production at the sectoral level show only limited asymmetries and not necessarily in energy intensive industries, as theory would have suggested."

We conclude that different countries respond differently to oil price shocks, and as noted by Serletis and Istiak (2013), this could be attributed to price and wage rigidities, varieties of macroeconomic policies in the different countries, and the nature of oil price shocks. In fact, as Kilian and Lewis (2011, p. 1066) put it in the case of the United States, "oil price shocks are best viewed as symptoms of deeper structural shocks in oil markets. One would expect the Federal Reserve to respond differently to oil price shocks associated with, say, unexpected booms in global demand, than oil supply disruptions. An unexpected demand boom driven by the global business cycle, for example, will stimulate the US economy in the short run, whereas an unanticipated oil supply disruption will not, calling for different policy responses depending on the composition of the oil demand and oil supply shocks underlying the oil price shock."

6 Conclusion

In recent years, emerging and developing economies accounted for about 70 percent of global growth in output and consumption, and in the aftermath of the global financial crisis, with advanced economies experiencing a slow recovery, the contribution of emerging market and developing economies to global growth has been even higher. Although the relationship between the price of oil and the level of economic activity in advanced economies has attracted considerable attention in the literature, there are relatively few studies that investigate the effects of oil price uncertainty and oil price shocks in emerging market economies. In this paper, we contribute to this literature by investigating the relationship between oil prices and the level of economic activity in the seven largest emerging market countries — Brazil, China, India, Indonesia, Mexico, Russia, and Turkey.

In the context of a multivariate GARCH-in-Mean VAR specification, that controls for lagged changes in global crude oil production and world economic activity, we find that oil price uncertainty has a negative effect on real output in India, Indonesia, Mexico, Russia, and Turkey, and a positive and statistically significant effect on real output in Brazil and China. This evidence is broadly consistent with the evidence that is available for advanced economies — see, for example, Bredin *et al.* (2011). In our investigation of whether the responses of real output in the EM7 countries to positive and negative oil price shocks are symmetric or asymmetric, we use the Kilian and Vigfusson (2011) impulse response function test and provide evidence of a symmetric relation in China, India, Indonesia, Mexico, and Turkey and of an asymmetric relation in Brazil and Russia.

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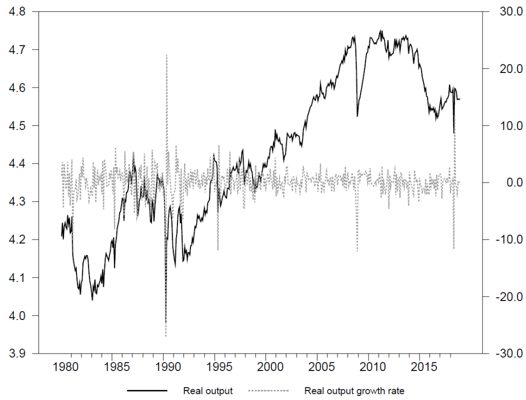
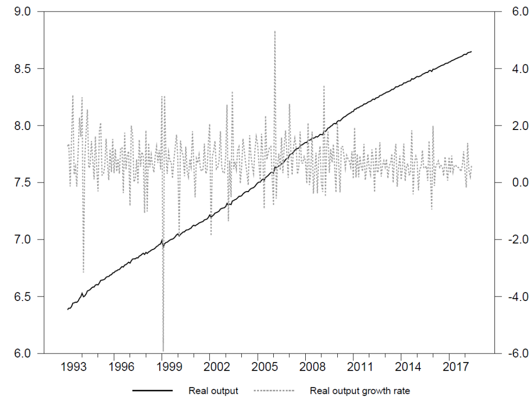
Figure 1. Real output and its growth rate for the EM7 countries

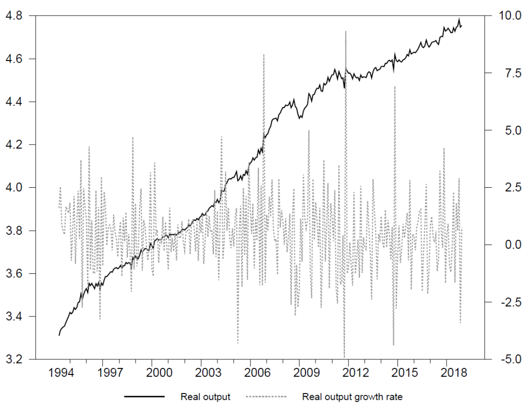
(a) Brazil



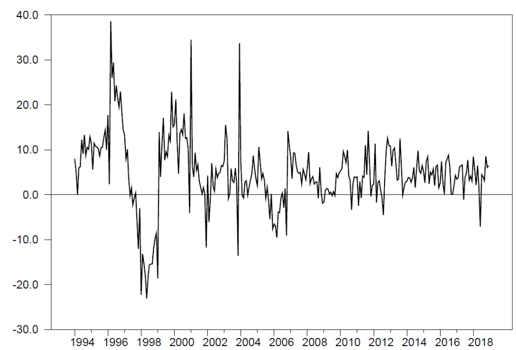
(b) China



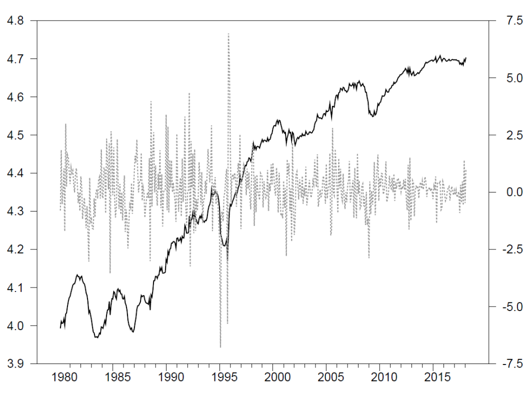
(c) India



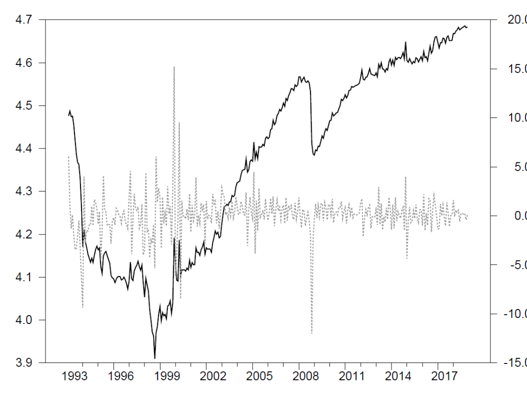
(d) Indonesia



(e) Mexico



(f) Russia



(g) Turkey

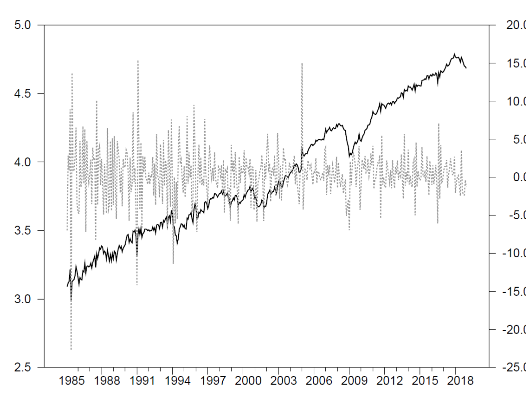
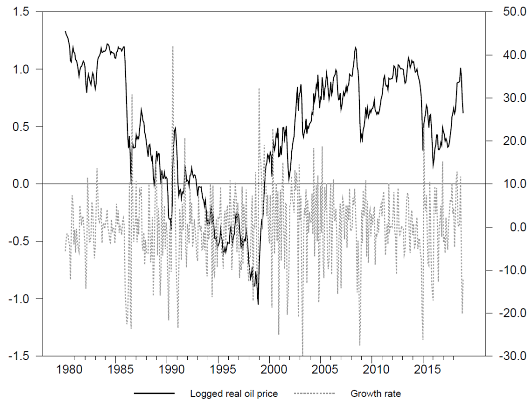
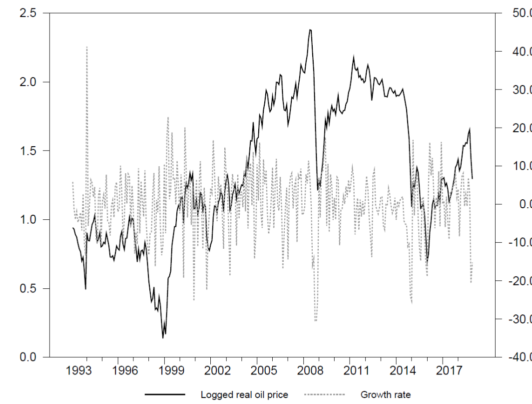


Figure 2. Brent crude oil price and its growth rate for the EM7 countries

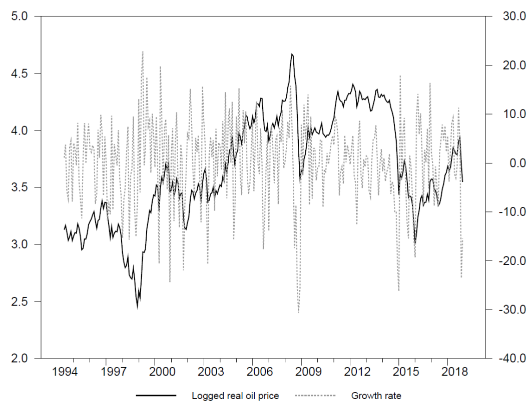
(a) Brazil



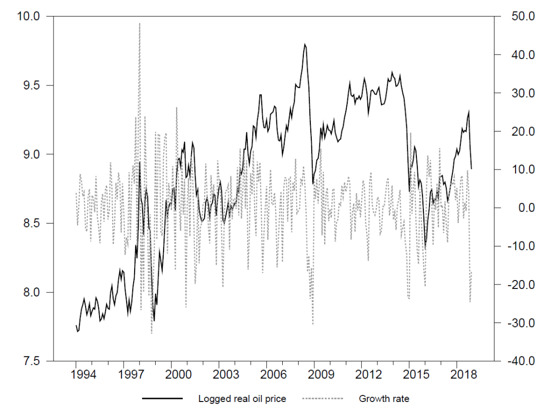
(b) China



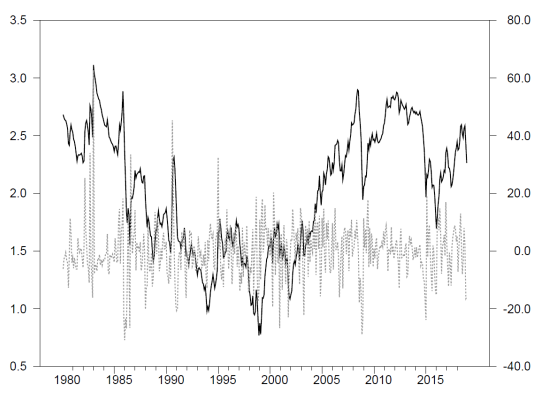
(c) India



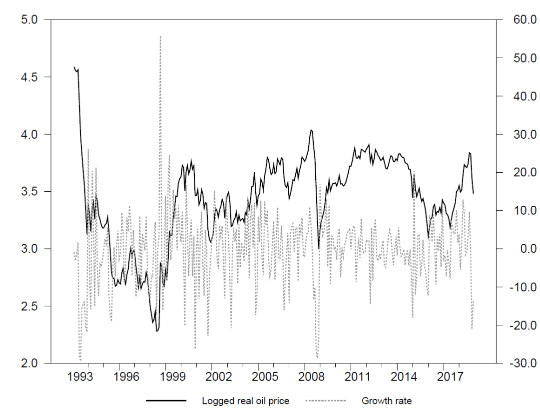
(d) Indonesia



(e) Mexico



(f) Russia



(g) Turkey

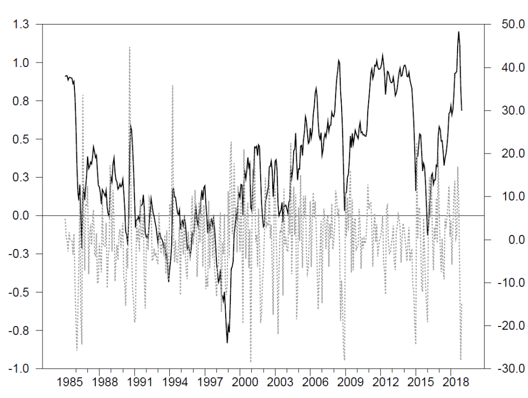


Figure 3. World crude oil production and its growth rate

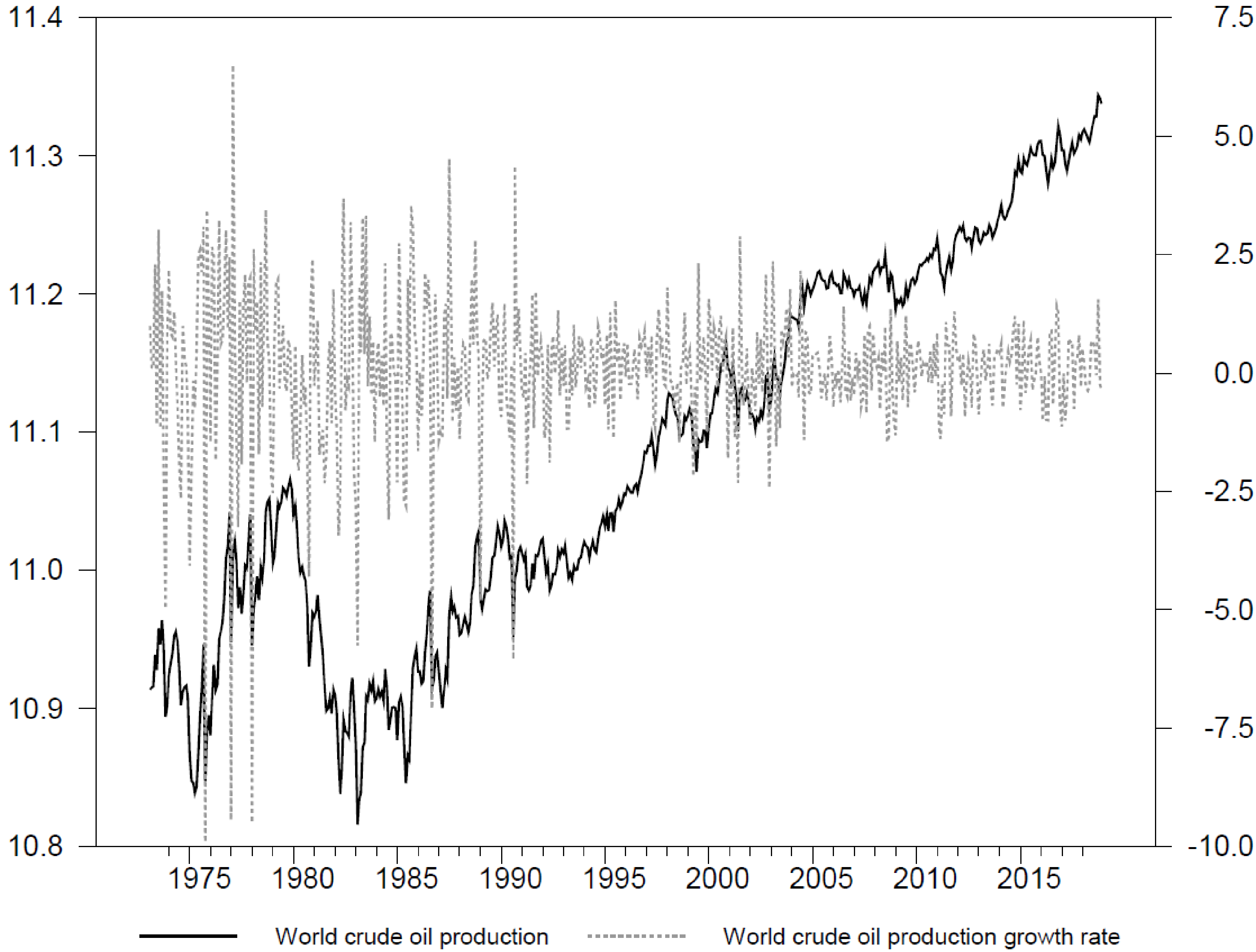


Figure 4. World economic activity

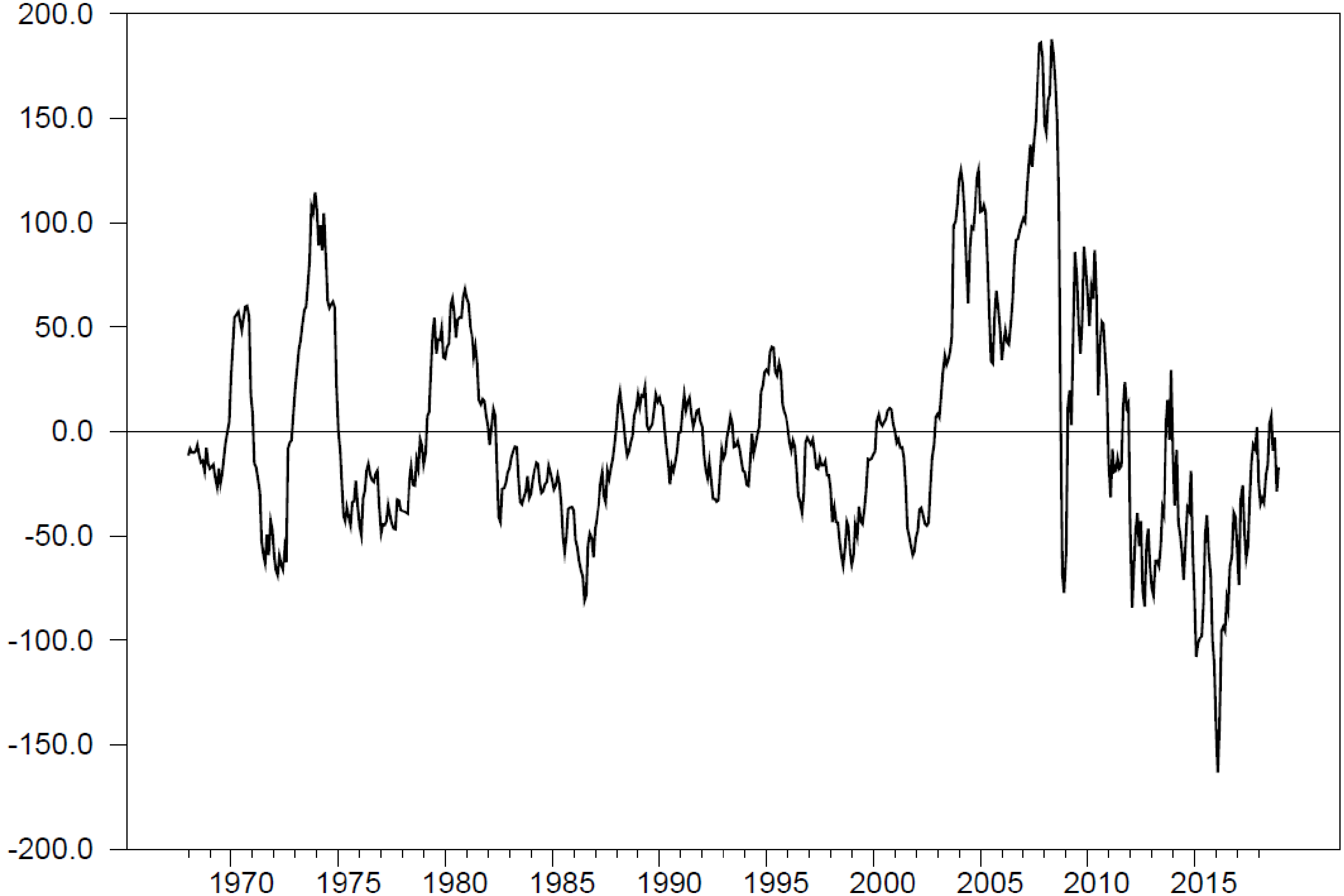


Table 1. Unit root and stationarity tests on the logged difference series

Country	ADF	PP	KPSS
(A.) Industrial production			
Brazil	0.000	0.000	0.072
China	0.000	0.000	0.179
India	0.000	0.000	0.068
Indonesia	0.019	0.000	0.061
Mexico	0.000	0.000	0.040
Russia	0.000	0.000	0.175
Turkey	0.000	0.000	0.040
(B.) Brent crude oil price			
Brazil	0.000	0.000	0.058
China	0.000	0.000	0.056
India	0.000	0.000	0.043
Indonesia	0.000	0.000	0.019
Mexico	0.000	0.000	0.049
Russia	0.000	0.000	0.129
Turkey	0.000	0.000	0.045

Notes: The first two columns report the p-values from the ADF and PP tests and the last column reports the KPSS test statistics. The 1% asymptotic critical value for the KPSS test is 0.216 for all the series.

Table 2. SIC values for the standard VAR and the multivariate GARCH-in-Mean VAR

Country	Homoscedastic VAR	GARCH-in-mean VAR
Brazil	17 951.151	16 886.016
China	9887.456	9498.109
India	10 386.066	10 183.709
Indonesia	9765.700	9299.102
Mexico	16 188.878	15 159.769
Russia	11 339.744	842.184
Turkey	15 884.714	15 189.324

Table 3. Coefficients of interest, $\hat{\lambda_{13}}$ and $\hat{\lambda_{43}}$, from the multivariate GARCH-in-Mean model

Country	Optimal lag length	$\hat{\lambda_{13}}$	$\hat{\lambda_{43}}$
Brazil	4	-0.024	0.021
		(0.000)	(0.021)
China	2	-0.044	0.013
		(0.000)	(0.072)
India	2	-0.056	-0.070
		(0.000)	(0.000)
Indonesia	3	-0.010	-0.030
		(0.012)	(0.000)
Mexico	2	-0.031	-0.065
		(0.000)	(0.000)
Russia	2	-0.006	-0.040
		(0.162)	(0.054)
Turkey	2	-0.035	-0.046
		(0.000)	(0.000)

Note: Numbers in parentheses are p values

Table 4. p-values for H_0:$I_y(h,\delta)$=$-I_y(h,-\delta)$, h= 0,1,2,3,4,5,6,7,8,9,10,11

	Brazil		China		India		Indonesia		Mexico		Russia		Turkey	
h	$\hat{\sigma}$	$2\hat{\sigma}$	$\hat{\sigma}$	$2\hat{\sigma}$	$\hat{\sigma}$	$2\hat{\sigma}$	$\hat{\sigma}$	$2\hat{\sigma}$	$\hat{\sigma}$	$2\hat{\sigma}$	$\hat{\sigma}$	$2\hat{\sigma}$	$\hat{\sigma}$	$2\hat{\sigma}$
0	0.591	0.600	0.226	0.243	0.411	0.410	0.020	0.026	0.122	0.120	0.000	0.000	0.022	0.017
1	0.001	0.002	0.271	0.302	0.334	0.324	0.067	0.082	0.074	0.073	0.001	0.000	0.060	0.045
2	0.001	0.002	0.297	0.332	0.527	0.518	0.142	0.171	0.073	0.072	0.001	0.001	0.131	0.102
3	0.003	0.005	0.438	0.478	0.687	0.677	0.240	0.281	0.137	0.135	0.002	0.002	0.213	0.164
4	0.006	0.009	0.578	0.618	0.792	0.792	0.309	0.355	0.222	0.220	0.003	0.002	0.323	0.257
5	0.012	0.017	0.670	0.718	0.849	0.838	0.426	0.477	0.226	0.221	0.005	0.004	0.441	0.366
6	0.021	0.030	0.760	0.808	0.901	0.899	0.515	0.563	0.317	0.312	0.005	0.004	0.558	0.478
7	0.034	0.046	0.839	0.877	0.800	0.832	0.623	0.669	0.416	0.407	0.009	0.008	0.652	0.573
8	0.050	0.066	0.889	0.919	0.868	0.890	0.717	0.755	0.506	0.493	0.010	0.009	0.744	0.671
9	0.070	0.093	0.932	0.952	0.916	0.932	0.786	0.821	0.601	0.588	0.012	0.010	0.820	0.753
10	0.068	0.089	0.879	0.923	0.948	0.960	0.829	0.866	0.680	0.670	0.016	0.013	0.878	0.823
11	0.094	0.122	0.921	0.952	0.969	0.977	0.835	0.865	0.752	0.740	0.024	0.018	0.919	0.877

Note Results are based on 10,000 impulse responses (R=10,000) and 50 histories (T=50)

Appendix Table A1. Data sources

	Variable	Source
Brazil	Industrial production	https://data.oecd.org/industry/industrial-production.htm
	Consumer Price Index: All Items	https://fred.stlouisfed.org/series/BRACPIALLMINMEI
	National Currency to US Dollar Exchange Rate: Average of Daily Rates	https://fred.stlouisfed.org/series/CCUSMA02BRM618N
China	Real GDP	https://www.frbatlanta.org/cqer/research/china-macroeconomy.aspx?panel=3
	Consumer Price Index: All Items	https://fred.stlouisfed.org/series/CHNCPIALLMINMEI
	National Currency to US Dollar Exchange Rate: Average of Daily Rates	https://fred.stlouisfed.org/series/CCUSMA02CNM618N
India	Industrial production	https://data.oecd.org/industry/industrial-production.htm
	Consumer Price Index: All Items	https://fred.stlouisfed.org/series/INDCPIALLMINMEI
	National Currency to US Dollar Exchange Rate: Average of Daily Rates	https://fred.stlouisfed.org/series/CCUSMA02INM618N
Indonesia	Industrial production	https://aric.adb.org/database/economic-financial-indicators
	Consumer Price Index: All Items	https://fred.stlouisfed.org/series/IDNCPIALLMINMEI
	National Currency to US Dollar Exchange Rate: Average of Daily Rates	https://fred.stlouisfed.org/series/CCUSMA02IDM618N
Mexico	Industrial production	https://data.oecd.org/industry/industrial-production.htm
	Consumer Price Index: All Items	https://fred.stlouisfed.org/series/MEXCPIALLMINMEI
	National Currency to US Dollar Exchange Rate: Average of Daily Rates	https://fred.stlouisfed.org/series/CCUSMA02MXM618N

	Variable	Source
Russia	Industrial production	https://data.oecd.org/industry/industrial-production.htm
	Consumer Price Index: All Items	https://fred.stlouisfed.org/series/RUSCPIALLMINMEI
	National Currency to US Dollar Exchange Rate: Average of Daily Rates	https://fred.stlouisfed.org/series/CCUSMA02RUM618N
Turkey	Industrial production	https://data.oecd.org/industry/industrial-production.htm
	Consumer Price Index: All Items	https://fred.stlouisfed.org/series/TURCPIALLMINMEI
	National Currency to US Dollar Exchange Rate: Average of Daily Rates	https://fred.stlouisfed.org/series/CCUSMA02TRM618N
Oil price	Crude Oil (petroleum), Dated Brent, light blend 38 API, fob U.K., US$ per barrel	https://www.imf.org/en/Research/commodity-prices
Oil production	Crude Oil Production, World (Thousand Barrels per Day)	https://www.eia.gov/totalenergy/data/browser/?tbl=T11.01B#/?f=M&start=200001
Economic activity	Global real economic activity index	https://sites.google.com/site/lkilian2019/research/data-sets

Appendix Table A2. Data description

Series	Transformation in baseline and alternative models	Description
$\triangle IP$	$100 * [ln(IP_t) - ln(IP_{t-1})]$	Industrial production growth rate
$\triangle PROD$	$100 * [ln(PROD_t) - ln(PROD_{t-1})]$	World crude oil production growth rate
$\triangle OIL$	$100 * [ln(OIL_t) - ln(OIL_{t-1})]$	Real price of crude oil (in domestic currency) growth rate
WEA	$12/100 * (WEA)$	Index of global real economic activity in industrial commodity markets