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Testing the Asymmetric Effects of Exchange Rate and Oil Price Pass-Through in BRICS Countries: Does the state of the economy matter?

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Abstract

This paper investigates not only the question of whether there is exchange rate and oil price pass-through (EROPPT) but also the extent to which the pass-through is asymmetric or state dependent in the BRICS countries. Using monthly data and the nonlinear Vector Smooth Transition Autoregressive (VSTAR) model, we find evidence of period specific pass-through between the upper and lower regime periods, governed by the selected transition variables. We also find asymmetric pass-through in all the countries with strong evidence of higher pass-through when the size of the shocks to the transition variable moves the system above a threshold level. The result further divulges that output growth asymmetrically reacts to the shocks. The implication of these findings is that the pass-through is strongly affected by the state of the economy.

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1. Introduction

One of the central issues within the framework of the new open economy macroeconomic models is the pass-through of exchange rate and oil price. This is largely triggered by two main factors: firstly, the persistent and high volatilities in terms of exchange rates between countries following the collapse of the Bretton Wood's system of adjustable peg in the 1970s and secondly, the severe impact of oil shocks, resulting from the perpetual crisis that has been erupting the Middle East since 1970s. Essentially, these factors have demonstrated an increased risk of achieving the monetary policy goal of price stability, especially in the developing and emerging markets economies during the periods of greater economic liberalization policies. (See McCarthy 2000; Compa *et al.* 2004; Gagnon and Ihrig 2004; Usman and Musa 2018).

There has been flourishing empirical literature on exchange rate and oil price pass-through (EROPPT) over the years and a great deal of it seeks to estimate the EROPPT to inflation using the linear models. The outcomes of the studies almost entirely suggest that the pass-through is incomplete and as such dampening along the price chains. In other words, the responsiveness of prices to exchange rate and oil price variations is not full or complete, particularly in the short to medium term. The major explanations given in the literature include the presence of the menu cost adjustment price, pricing-to-market, trade hysteresis, degree of market competition, and the stance of monetary policy (See Taylor 2000; Choudhri and Hakura 2003; Bailliu and Fujii 2004; Ihrig *et al.* 2006; Atkeson and Burstein 2008; Junttila and Korhonen 2012; Kilic 2016).

Even though the literature on pass-through has increased particularly in the new millennium, many studies assume that the direction and the size of the shocks in exchange rate and oil price do not matter for pass-through. However, this assumption has been challenged by the recent literature that domestic prices may possibly react asymmetrically to the shocks in exchange rate and oil price especially when domestic prices are strictly downward sloping and quantities are upward sloping (Delatte and Lopez-Villavicencio 2012; Baharumshah *et al.* 2017a; Usman and Elsalih 2018). The objective of this paper is to investigate not only the question of whether there is evidence of nonlinear EROPPT in the bloc of Brazil, Russia, India, China and South Africa (henceforth BRICS Countries). If the EROPPT is nonlinear, not only the pass through is asymmetric but also the sign and size of the shocks matter. The choice of the BRICS countries is motivated by large changes in exchange rates and trade policies towards market-based economic policies. These changes, however, demonstrate a significant increase in the share of BRICS countries to the total volume of the world trade. As shown by Enerdata (2015), the total share of BRICS in the total volume of world trade is USD 7.7 trillion, which accounts for about 18%. This statistic is about 70.5% higher than the total of USD 4.4 trillion in 2008. The worrisome implication of the increase in trade when exchange rate is allowed to float freely is the exposure of these economies to the effects of exchange rate and oil price volatilities. Therefore, investigating the dynamics of pass-through of exchange rate and oil price are essential for the proper management of macroeconomic policies and a sound understanding of the process of price determination, which is a key issue in monetary policymaking.

Theoretically, the behaviours of the exporting firms are strategically guided by the market share objectives, which perhaps creates a difficult environment to fully pass-through the changes in exchange rate and oil price to domestic prices. If the size of the change in exchange rate and oil price is less than a certain threshold (small) and the changes in price are costly, the firms may prefer to absorb it and leave their prices unchanged, leading to zero pass-through. There are two main reasons to support this argument. First, it allows exporting firms to gain and maintain market share and secondly, the cost required to change prices (price adjustment cost or menu cost) exceeds the revenues that the exporting firms generate from price adjustment. Furthermore, if the size of the change in exchange rate is more than a certain threshold (large), the exporting firm would adjust their exporting price in such a way that their mark-ups will absorb a certain change and pass-through some change into export prices, leading to incomplete pass-through. Finally, if import prices are set in the currency of an exporting country, a small or large shock does not change the prices received by the domestic firms hence EROPPT is complete. Although if import price is set in the currency of an importing country, the pass-through tends to be stronger when the shock is somewhat large than when the shock is somewhat small (See Dornbusch 1987; Baldwin 1988; Pollard and Coughlin 2004).

While studies on the asymmetric exchange rate pass-through (ERPT) abound for developed and developing economies, there are only a small number of studies focusing on the responses of the prices to the change in exchange rate and oil price in different state or regime of the economy. Such regime dependent ERTP can be represented by a nonlinear model, such as the VSTAR. In a VSTAR model, responses are asymmetric, implying they are period specific (history matters) and both the sign and size of shocks alter responses. For example, Aron *et al.*

(2014) analyze the ERPT to monthly price index in South Africa for the period of 1980-2009 and report that ERPT is higher during a small appreciation of rand. This result is contrary to Karoro *et al.* (2009) who find that the pass-through during a depreciation is higher than an appreciation in South Africa. Similarly, a study by Jooste and Jhaveri (2014) affirm that a decline in the pass-through in South Africa is attributed to a low and stable inflation environment. This group of findings in South Africa is congenial to Pollard and Coughlin (2004), Junttila and Korhonen (2012), Shintani *et al.* (2013), Ben Chiekh and Louhichi (2016), Kilic (2016), Jimenez-Rodriguez *et al.* (2016) and Soon *et al.* (2017). In China, Apergis (2015) finds asymmetric evidence of the ERPT to poverty with the period of depreciation of the Chinese currency having a stronger pass-through impact than when Chinese currency appreciates. In addition, Bouvet *et al.* (2017) find evidence that the pass-through of the exchange rate to Chinese exports is almost complete between 2000 and 2006 on the basis of firm-level data. In the case of Russia, Kataranova (2010) indicates that consumer prices react to the depreciation of home currency than appreciation. This finding is, however, contrary to Ponomarev *et al*. (2016) who show that the depreciation of domestic currency causes prices to rise but the appreciation of it does not lead to a fall in prices. In Brazil, Albuquerque and Portugal (2005) apply the time-varying parameters to investigate the ERPT to inflation during the period of 1980-2002. This finding discloses a significant reduction in the pass-through estimation during the era of post-floating of exchange rate. Similarly, Correa and Minella (2010) investigate on the basis of Phillips curve, whether the short run pass-through of exchange rate in Brazil is affected by the business cycle, exchange rate volatility and the direction of exchange rate. Among the findings discovered is that the short run pass-through is stronger during the periods of the high growth of the economy and low volatility of exchange rate. More so, Macera and Divino (2015) demonstrate that deterioration of trade following the long-run effect of the variable shocks during an appreciation of the exchange rate offset the effect of import tariffs in Brazil. Furthermore, in the case of India, Yanamandra (2015) provides that import prices at the aggregated level are slightly different with evidence of more than complete pass-through in the short run and even higher in the long run. This finding also shows evidence of nonlinearity in the ERPT in terms of the direction and the size of the changes in the exchange rate.

While there is a growing interest in the literature of oil price-inflation nexus, several studies abound for developed countries leaving a missing gap for the developing and emerging economies. Hooker (2002) using the framework of Phillips curve, discovers that oil price shock directly contributes to core inflation before 1980, and after which the pass-through becomes dampened and sometimes zero in the US. This decline is largely attributed to the proper implementation of monetary policy, flexible labor markets and lower intensity of energy use by the industries. De Gregorio *et al.* (2007) report that oil price pass-through (OPPT) to consumer prices for the sample of thirty-seven industrialized and emerging countries for the past thirty years has drastically reduced compared to the pass-through in the 1970s and 1980s. More so, Valcarcel and Wohar (2013) find that the effect of oil prices on inflation and economic activity has dropped substantially in the advanced countries. On the contrary, Baharumshah *et al.* (2017b) show that the OPPT to domestic inflation is revived during the period of post-inflation in Mexico.

Furthermore, Asghar and Naveed (2015) examine the long-run OPPT to inflation in Pakistan and provide evidence of positive interaction between oil price and inflation as well as establish a one-way causality, running from oil prices to inflation and again from oil price to exchange rate. This finding is perhaps related to Sek (2017) who divulges that oil price is connected to high output growth in Malaysia through an increase in import and production prices. Therefore, a sector with high oil-intensiveness tends to experience a larger pass-through of oil prices. Furthermore, a study by Balcilar *et al.* (2017) reveal that real output growth under the low growth episode can be adequately predicted by the oil price shocks in South Africa business cycles; however low output growth episode is smaller compared to the high output growth episode. In the same development, Kpodar and Abdallah (2017) document that the positive shocks of oil price is more effective on retail gasoline prices in the 162 countries. Finally, Balcilar *et al.* (2018a) explicitly disclose that oil price and inflation are related, with the positive shock in oil price having a stronger effect on inflation compared to the negative shock of the same size. Balcilar and Usman (2018) examine both ERTP and OPPT for BRICS countries using Diebold and Yilmaz (2009) spillover index methodology. They find strong evidence of directional spillover in all the countries, but the results are somewhat heterogenous across the countries. Our study differs from Balcilar and Usman (2018) in two important ways. Balcilar and Usman (2018) use a linear VAR model and spillover indexes to asses ERTP and OPPT. Our study considers nonlinearity and focuses on state dependence. We also use bootstrap based impulse functions as the main analysis tool to assess the pass-through dynamics, which has advantages over the analysis based on asymptotic results.

Despite a burgeoned empirical evidence on pass-through, some numbers of issues remain contentious, such as whether the changes in policy directions of exchange rate and trade policy towards liberal economic policies exert pressure on the pass-through channels. In addition, the extant literature mostly focused on the pass-through of exchange rate changes to import prices, which is known as the first stage of pass-through. In testing for pass-through in this paper, our analysis switches from first stage pass-through to the second stage, which focuses on the pass-through to inflation following changes in exchange rate and oil price. Therefore, our study contributes to the existing literature based on the following aspects: First, we investigate whether there is evidence of nonlinearity in the EROPPT for the BRICS countries and further investigate whether the asymmetry of the shocks to exchange rate and oil price matter for EROPPT in these countries, an aspect that has received less attention in the literature. Second, our paper uses a country-specific analysis based on time series. Even though the BRICS countries are considered as a bloc of the fast-growing economic hub of the emerging markets in the past two decades (See IMF, 2011), it is obvious that the country-specific analysis will shed more light on the dynamics of asymmetric EROPPT and provide better outcomes due to the heterogeneous nature of pass-through estimates in these countries. Third, methodologically, the paper applies the VSTAR model, which allows for the smooth transition of the economy from one particular regime periods to another regime periods, governed by the selected transition variables. Fourth, for a better understanding of the dynamics of asymmetric EROPPT, we explore a bootstrapping approach where the generalized impulse responses based on history, shocks, and composition dependent are obtained with 1000 bootstrap repetitions since there is no clear-cut analytical formula to obtain the impulses of VSTAR models.

The main findings of this paper are as follows: there is evidence of period specific pass-through between the upper and lower regime periods, governed by the selected transition variables. The findings also suggest an asymmetric pass-through in all the countries with strong evidence of higher pass-through when the size of the shocks to the transition variable moves the system above a threshold level. The result further discloses that output growth asymmetrically reacts to the shocks. The implication of these findings is that the pass-through is strongly affected by the states of the economy.

The remainder of the paper is organized as follows: Section 2 discusses the data and the preliminary analysis of the data. Section 3 contains the discussion of the econometric methodologies explored. Section 4 discloses the results and discussions while section 5 makes conclusions of the paper.

2. Data and preliminary analysis

We use monthly frequency data for the BRICS countries in this paper. Specifically, the data for Brazil and India spans from 1986M01-2018M04, China and South Africa span from 1990M01-2018M04, and for Russia, the data ranges from 1995M01-2018M04. These periods selected for each country are influenced by the availability of data. The consumer price index (CPI), exchange rate, and oil price are the main variables of interest. However, output growth is added as a control variable. The CPI is measured in terms of the seasonally adjusted CPI, exchange rate is measured as the nominal broad effective exchange rate (NEER) and output growth is measured in terms of the seasonally adjusted industrial production index (IPI).[1] For crude oil price (OIL), we collect the spot price of oil in USD per barrel and multiply it by the nominal exchange rate of each country to obtain the crude oil price in terms of local currency. The data on CPI is obtained from the database of the International Financial Statistics (IFS) database of the International Monetary Fund (IMF). The data on NEER and IPI are sourced from the Thomson Reuters DataStream while data on crude oil price (in USD) is obtained from the US Energy Information Administration (EIA, 2018). Following Balcilar *et al.* (2017; 2018b), we convert the series into their natural logarithms to ensure the stability of the variance.

Before we estimate the model, it is required that the variables must be stationary. The results of the stationarity properties of the variables based on the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests divulge that all the series are only stationary in their first differences, I(1) (see Balcilar and Usman 2018). Therefore, our analyses are based on the log-growth rate in percent, which is expressed as $\log(y_t/y_{t-1}) \cdot 100$, where y_t is the level variable, and y_{t-1} is the one-lag value of the level variable. One of the advantages of using variables at the first difference is that it makes the VAR model stable if the variables are possibly nonstationary (see Lütkepohl 2005).

Table 1 discloses the descriptive statistics of the monthly frequency data on CPI, IPI, NEER, and OIL variables for the BRICS countries. Panel A unveils the statistical characteristics of the

[1] Due to insufficient data on industrial production index in the case of South Africa, the manufacturing production index (MPI) is used to measure output growth.

variables expressed in their natural logarithms while Panel B divulges the statistical characteristics of the variables in their log-differences (log growth rate). The total number of observations in the case of Brazil and India is 388 and 387 for log-level and log-difference. For China and South Africa, it is 340 and 339 while Russia is 280 and 279 respectively. Following the result in Panel A, the largest and smallest mean for NEER and CPI is found in Brazil with the values of 7.67 for log level and 1.02 for log-difference. Pertaining to Panel B, the largest and lowest mean is found to be CPI and IPI with the values of 5.59 for log-level and -5.17 for log-difference. Furthermore, we find that in Russia, India, China, and South Africa, oil price is found to have the largest mean as divulged in Panels A and B respectively. The largest variability is found to be oil price for Brazil, followed by Russia, South Africa, India, and China. This volatility is more conspicuous in their log-differences (Panel B) across the BRICS countries. The skewness of the variables discloses that some of the variables captured in this study are skewed to the right (positively skewed) and others are skewed to the left (negatively skewed). In addition, the variables exhibit positive kurtosis in both panels leading to leptokurtic distribution. Consequently, we reject the null hypothesis of normal distribution at a 1% level of significance for all the countries. This perhaps implies that the distribution of the variables grossly departs from normality path in the BRICS countries. The nonnormality of all series implies that nonlinear VAR models such as the STVAR we consider represent the time series properties of the data better than the linear alternatives.

Figs. 1 to 5 disclose the time series plots of OIL, CPI, NEER, and IPI based on their log-levels. Fig.1 illustrates the time plots for Brazil, which show that OIL and IPI exhibit upward movement up to 1995, after which they become relatively constant. This, therefore, implies co-movement between OIL and IPI. The case of NEER slopes downward until it settles down in 1995, suggesting depreciation of currency while CPI shows evidence of upward random movement with fluctuations over the years. Figs. 2, 3, and 5 divulge the time plots of Russia, India, and South Africa. The figures exhibit similar characteristics in these countries. The OIL and CPI demonstrate profoundly an upward movement with evidence of time-trend. On the other hand, the NEER and IPI show evidence of fluctuations, which are apparently more noticeable in IPI. As we can easily see, the NEER slopes downward while IPI slopes upward until the recent drop in the prices of the international crude oil erupted in 2014. This perhaps affects the output growth significantly in these countries. Finally, the case of China shows evidence of large fluctuations and structural breaks in all the variables, but no clear-cut evidence of time trends is noticeable. The figure further reveals several spikes in the CPI.

3. Econometric methodology

This section presents our strategy to investigate an asymmetric EROPPT to inflation in the countries of BRICS. This strategy is based on the VSTAR model, which allows for an economically relevant smooth transition from one particular regime periods to another regime periods, governed by the selected transition variable. Therefore, following Anderson and Vahid (1998), Weise (1999), Camacho (2004), Auerbach and Gorodnichenko (2012), Teräsvirta and Yang (2014), and Balcilar *et al.* (2016, 2018b), among others, who extended the smooth transition autoregressive threshold models to a multi-equation setting based on the single-equation introduced by Teräsvirta and Anderson (1992), our STVAR model is specified as:

$$Y_t = \mu^1 + \sum_{i=1}^{p} \Phi_i^1 Y_{t-1} + \left(\mu^2 + \sum_{i=1}^{p} \Phi_i^2 Y_{t-1}\right) F(z_t;\gamma;c) + \epsilon_t \tag{1}$$

where $Y_t = (Y_{1t}, Y_{2t}, \dots, Y_{Nt})'$. Indeed, the number of variables, N is 4 hence, Y_{1t} is $\Delta\mathrm{OIL}_t$, Y_{2t} is $\Delta\mathrm{NEER}_t$, Y_{3t} is $\Delta\mathrm{CPI}_t$ and Y_{4t} is $\Delta\mathrm{IPI}_t$. Notes that $\Delta x_t = x_t - x_{t-1}$ with x_t representing OIL, NEER, CPI, and IPI are oil price, nominal effective exchange rate, consumer price index and industrial production index in natural logarithms.[2] The scalar transition function, $F(z_t;\gamma,c)$ is bounded between zero (lower regime) and one (upper regime). These two extreme values correspond to the lower regime periods and upper regime periods respectively.

In this study, we assume that the transition function is a logistic function, expressed as:

$$F(z_t;\gamma,c) = [1 + \exp\{-\gamma(z_t - c)\}]^{-1} \tag{2}$$

where γ represents the smoothness (adjustment speed), which determines whether the transition between lower regime periods and upper regime periods is sharp or smooth; $c\ is$ the threshold, and z_t is the state or transition variable, which is selected as $z_t = Y_{it-d}$, where i denotes OIL, NEER, CPI, and IPI and d is the delay. As the smoothness parameter approaches infinity, the transition function is reduced to the indicator function; hence, the model becomes a threshold VAR (TVAR) advanced by Tong (1983).[3] However, if the smoothness parameter

[2] Note that other vectors and matrices are defined analogously.

[3] The indicator function, $I(z_t)$ is captured by 1 if $z_t > c$ and 0 if $z_t < c$.

approaches zero, the transition function converges to a constant, and hence the model becomes linear, as the nonlinear part is redundant. The time index $t = 1,2,3, \dots, N$, upper regime periods are $t_u \in \{t_{u1}, t_{u2}, \dots, t_{uN_u}\}$, $N_u < N$, such that for each t_{ui}, $i = 1,2, \dots, N_u$, $z_t > c$, i.e. $t_u = t|z_t > c$. Analogously, lower regime periods are defined as the set $t_l \in \{t_{l1}, t_{l2}, \dots, t_{lN_l}\}$ such that $t_l = t|z_{t-d} < c$. Note that $N_u + N_l = N$.

As well established in the literature, testing for linearity before fitting a nonlinear model is the first step in building nonlinear models. To this end, we first perform *F* version of the linearity test and the Likelihood Ratio (LR) linearity test using the 1-st, 2-nd and 3-rd order Taylor expansions as described in Teräsvirta and Yang (2014), to solve the problem of identification under linearity. We test the null hypothesis of $H_0: \gamma = 0$ i.e. linearity against the alternative $H_1: \gamma > 0$ i.e. nonlinear (VSTAR) model. The LM linearity test can be carried out equation by equation by excluding all the nonlinear parameters in the equation as described by Teräsvirta and Anderson (1992) and Weise (1999). To perform this test, we follow a three-step procedure, which includes the following:

The first one is to consider each restricted regression of *k*-variable linear VAR with *p* lags model in Equation (3) and obtain residuals $\hat{u}_{it}$ with the sum of squared residuals clearly define as $SSR_0 = \sum \hat{u}_{it}^2$.

$$Y_{it} = \beta_{i0} + \sum_{j=1}^{pN} \beta_{ij} W_{jt} + u_{it} \tag{3}$$

In the second step, we run the unrestricted regression that appears in Equation (4) and obtain residuals $\hat{v}_{it}$ with the sum of squared residuals define as $SSR_1 = \sum v_{it}^2$.

$$u_{it} = \alpha_{i0} + \sum_{j=1}^{pN} \alpha_{ij} W_{jt} + \sum_{j=1}^{pN} \delta_i z_t W_{jt} + v_{it} \tag{4}$$

Finally, we, therefore, compute the LM test statistics from the results obtained in Equations (3) and (4) as:

$$LM = \frac{T(SSR_0 \times SSR_1)}{SSR_0} \sim \chi^2(pN) \tag{5}$$

where T denotes the number of observations. More so, the LR linearity test for excluding all nonlinear parameters in all the equations is performed to assess the linearity based on the whole system as described in Weise (1999). To compute the asymptotically distributed LR test statistic given as $LR = T\{\log|\Omega_0| - \log|\Omega_1|\} \sim \chi(pN^2)$, where $\Omega_0 = \sum \hat{u}_t\hat{u}_t'/T$ and $\Omega_1 = \sum \hat{v}_t\hat{v}_t'/T$ are the estimated variance-covariance matrices of the residuals based on the restricted and unrestricted regressions in equations (3) and (4). The decisions for both F and LR linearity tests are based on the bootstrapped p-values obtained with 1000 bootstrap repetitions. This helps to circumvent bias and imprecise inferences using asymptotic p-value due to nonstandard distributional and finite sample problems.

In addition to the F and LR linearity tests, we apply the system linearity test proposed by Rao (1973), which uses the Rao's version of the F-test (F_{RAO}) for the exclusion of the nonlinear parameters in all the equations. The test is computed as follows:

$$F_{RAO}(k) = \left(\frac{1 - \Lambda^{\frac{1}{s}}}{\Lambda^{\frac{1}{s}}}\right)\frac{\delta s - \frac{1}{2}(Nk - 2)}{Nw} \tag{6}$$

where $\Lambda = |\widehat{\Omega}_1|/|\widehat{\Omega}_0|$, represents the Wilk's Lambda, $w = k(pN + 1)$, $s^2 = (N^2w^2 - 4)/w^2 + N^2 - 5)$, $\delta = T - (1 + pN) - \frac{1}{2}(N + w + 1)$, k is order of the Taylor expansion, and the F_{RAO}-statistic is approximately distributed as $F\left(Nw, \delta s - \frac{1}{2}(Nk - 2)\right)$ under the null hypothesis. The decision rule in respect of this test is similar to F and LR linearity tests.

4. Results and discussions

4.1 Linearity tests

The first stage in this section is the presentation of the first-round linearity tests. Table 2 presents the results of the F and LR linearity tests based on a standard 4-dimensional VAR model using transition variables for each equation based on the a priori selection as indicated in Balcilar *et al.* (2016). The F_{RAO} tests are given Tables 3(a)-(e). The lag order is chosen by the Schwarz Information Criterion (SBC) and 1 for all countries. The results based on the bootstrapped p-values with 1000 repetitions provide substantial evidence to reject the null hypothesis of a linear VAR in favor of a nonlinear VAR (VSTAR) model in each of the equations and the system as a whole. We select the transition variable based on the minimum p-value and majority of the rejection of linearity for each of the dependent variables using the results presented in Table 2. Therefore, on the basis of these results, $\Delta\mathrm{OIL}_{t-1}$ is selected as the transition variables (z_t) for Brazil and Russia, $\Delta\mathrm{IPI}_{t-1}$ is selected for China and India, while $\Delta\mathrm{NEER}_{t-1}$ is selected for South Africa.

4.2 VSTAR estimations

We estimate the multivariate unrestricted VSTAR model using nonlinear least squares, which is based on equation (1). The results of the estimations are divulged in Tables 3(a)-(e) where the upper regime periods and lower regime periods correspond to the pass-through estimates determined by the conditions $z_t \leq c$ and $z_t > c$, respectively. The estimates of the speed of adjustment and the threshold parameters are reported for each country with their corresponding p-values. Particularly, the estimates of the speed of adjustment parameters γ show the existence of a smooth transition between the upper and lower regimes with Brazil having the largest estimate, followed by Russia, India, China, and South Africa. However, it is evident in all countries that γ is larger than zero and statistically significant in Brazil and China.[4] In addition, the estimate of the threshold parameter c, is positive and significantly higher than zero in all the countries, indicating an asymmetric EROPPT for all the countries investigated. However, the fact that the adjustment speed estimates are distantly higher than zero in all the countries suggest the existence of the low-cost of price adjustment, which encourages firms to easily adjust their prices to small and large changes in exchange rate and oil prices. This result is contrary to the theoretical conjecture described in Pollard and Coughlin (2004) that a small shock to exchange rate is likely to be absorbed within the firms' mark-up margins because of the high cost of price adjustment (menu cost). In overall, the possibility of adjusting prices to a small and large shock to exchange rate and oil price is higher in Brazil, followed by in China, India, South Africa, and Russia.

The coefficient estimates of the VSTAR models for all the countries as disclosed in Tables 3(a)-(e) show the responses of the CPI, IPI, NEER, and OIL to the shocks in NEER and OIL

[4] As noted by van Dijk (2002) the smoothness parameter is difficult the estimate and its estimation precision is low. Thus, statistical tests on the smoothness parameter should are not reliable.

in these countries. The results based on the model estimations show that the variables respond positively and negatively to the shocks in all the equations with evidence of asymmetry, which is possibly determined by the dynamic interactions among the investigated variables both in the upper and lower regime periods. These results could be traceable to exchange rate and oil price volatilities. This finding is similar to Balcilar *et al.* (2016) who depicted that the responses to shocks in the logistic STVARs dynamically interact and co-move in the lower regime, corresponding to the period of financial tightening and financial volatility and the upper regime periods, which corresponds to the stable and loose financial conditions' periods.

Furthermore, we perform equation by equation F-linearity, the system LR linearity, and the system F_{RAO} linearity tests in the models using the selected transition variables for each country investigated. These tests are different from the *F* and LR tests in Table 2 since they test the null hypothesis that coefficients on the estimated variable $F(z_t; \hat{\gamma}, \hat{c})$ are jointly zero.[5] The results of *F* statistic indicate that with the exception of Brazil, there is no evidence to reject the null hypothesis of linearity in all the remaining countries when we used OIL as transition variables. However, the results of the system linearity test (i.e. LR and Rao's *F*-test) apparently provide strong evidence congenial to nonlinearity in all the equations with ΔOIL_{t-1} as a transition variable for Brazil and Russia, ΔIPI_{t-1} for India and China as well as ΔNEER_{t-1} for South Africa. This suggests that the shocks to each of the variables have asymmetric effects. In other words, the shocks to NEER and OIL have asymmetric pass-through effects on inflation in BRICS countries.[6]

4.3 Generalized Impulse Response Functions (GIRFs)

The coefficient estimates based on the VSTAR model may not make much meaningful interpretation rather than exposing the shape and position of the speed of adjustment and threshold parameters. To properly understand the dynamic behaviors of the variables and make more meaningful and insightful interpretations, most studies used impulse response functions (IRFs) as suggested by Sim (1980). In the nonlinear literature, there is no clear-cut analytical point formula to construct nonlinear IRFs because the impulse responses and the size of the shocks are not proportional, neither do they independent of the "history". To address this

[5] Following Balcilar *et al.* (2016), the *F*-tests applied are based on the Wald statistics with the heteroscedasticity-consistent matrix proposed by White (1980). Inferences are taken based on the bootstrapped *p*-values.
[6] The selection of transition variables, z_t for each of the equations is based on the LM_3 test for linearity, LR test and Rao F test for exclusion of the nonlinear part.

problem, the generalized impulse responses (GIRFs) are proposed by Koop *et al.* (1996), which can be based on bootstrap or Monte Carlo method. The bootstrap based GIRF method is used by Weise (1999) and recently used by Rahman and Serletis (2010), Balcilar *et al.* (2016; 2018b).

According to Weise (1999), unlike the linear IRFs, which assume that the shocks are invariant to "history" (i.e. the starting value), the nonlinear IRFs assume that the shocks are based on a specific "history". In other words, the "history" of the variables is considered as a random variable. Likewise, the effects of shocks in the future are inconsequential or rather considered insignificant in the linear IRFs; whereas for nonlinear IRFs, "the future shocks are drawn from some distribution and their effects averaged out over a large number of draws" (Weise, 1999:105). Furthermore, the linear IRFs do not vary with the size and magnitude of the shocks, whereas in the nonlinear IRFs the responses to shocks are notably determined by their sizes and magnitudes.

Specifically, to compute the multivariate GIRFs, we assume that Y_t denotes a random vector, v_t represents the shock that causes GIRF, and ω_{t-1} is the history of the variables "starting values" Hence,

$$\varphi_Y\left(n, v_{t,} w_{t-1}\right) = E\left[Y_{t+n} \middle| v_{t,} \omega_{t-1}\right] - E\left[Y_{t+n} | \omega_{t-1}\right],\ n = 0, 1, 2,3, \dots \tag{7}$$

where φ_Y represents the GIRFs of Y_t, n denotes the forecast horizon while $E[\cdot]$denotes the expectations operator. GIRFs of the STVAR model are history dependent, thus, we evaluate the GIRSs by taking distinct sets as the history. The upper regime period GIRFs are obtained by randomly drawing the history ω_{t-1} from the set $t_u \in \{t_{u1}, t_{u2}, \dots, t_{uN_u}\}$. Analogously, we obtain the lower regime GIRFs with random histories ω_{t-1} drawn from the set $t_l \in \{t_{l1}, t_{l2}, \dots, t_{lN_l}\}$. The results of the GIRFs are divulged in Figures 6 to 15.[7] We set the size of the shock v_t to one standard deviation the shocked variable. As all variables are in log first differences the NEER shock represents a one standard deviation appreciation while the OIL shock represents a one standard deviation increase in the price of oil in the local currency unit.

[7] For the purpose of this study, the "regime specific" impulse responses obtained with 1000 bootstrap repetitions go with the "period specific" term.

Thus, responses also in growth rate terms. The results as already mentioned are obtained with 1000 bootstrap repetitions and 95% confidence interval. The responses of the variables are computed for 25-month forecast horizon for Brazil while for Russia, India, China, and South Africa, the responses are computed based on the period of 10-month forecast horizon. These periods are sufficient to evaluate the responses of the variables to the shocks in NEER and OIL in the BRICS countries.

4.3.1 Responses to NEER shocks

As reported in Figures 6 to 15, we track the pass-through of NEER shocks to OIL, CPI, NEER, and IPI to NEER and OIL shocks in the BRICS countries in both the upper regime periods and the lower regime periods. Specifically, Figures 6 to 10 analyze the pass-through of NEER shocks to all the variables in our models including own-shocks while Figures 11 to 15 present the pass-through of OIL shocks to all the variables including own-shocks. In Figures 6(a)-(h) the pass-through of the shocks in NEER to OIL, CPI and IPI is divulged for Brazil. The pass-through to OIL, CPI and IPI is negative in the upper regime periods. This pass-through is statistically significant for OIL and CPI, and dampens gradually and smoothly until it stabilizes to the steady state (equilibrium) after twenty months. In the case of IPI, the pass-through is not significant for the first three months, after which it becomes significant and decreasing smoothly after the first month until it becomes neutral in the fifteen months. More so, the pass-through of own-shock (innovation) is positively significant and dampening to its equilibrium value after twenty months. In the lower regime periods, the pass-through to OIL, CPI, and IPI is negative and insignificant, while the pass-through of own-shocks is positive and significant. The pass-through gradually stabilizes to the steady state after ten months for all the variables. As can be seen further, the pass-through declines instantaneously in the first month, after which the pass-through becomes smooth and slow in all the variables. The smoothness in the pass-through indicates some delays on the pass-through channels in stabilizing to its equilibrium value. This delay is influenced by the stance of monetary policy and Central Bank credibility, which is the major argument in the recent pass-through literature (Aleem and Lahiani, 2014; Dube, 2016; Kabundi and Mlachila, 2018). Furthermore, comparing the size of the pass-through between the two regime periods, our results suggest a higher pass-through in the upper regime periods to the lower regime periods for all the variables.

The pass-through of the NEER shocks to all the variables in Russia is reported in Figures 7(a)-(h). In the upper regime periods, the pass-through to OIL and IPI is positive within the first month. This crosses to negative where they begin to rise instantaneously in the first month and reduce sharply in the second month until the pass-through is stabilized in the fourth and second month horizons respectively. The pass-through of own-shocks is positive and significant up to the second month after which it becomes neutral. Also, the pass-through to CPI is negative and insignificant. It therefore becomes positive in the first month, after which it turns significant until it stabilizes to its equilibrium in the second month. In the lower regime periods, the pass-through to OIL, NEER, and IPI is positive. In the case of OIL, the pass-through is not statistically significant while for IPI, it is statistically significant up to the second month. Finally, the pass-through to CPI is negative and insignificant; this gradually declines and becomes neutral after second month. Following these results, it can be seen that with the exception of the pass-through to OIL, which is smooth and slow, the pass-through is high-pitched for Russia. Although there is noticeable difference in terms of the size of the pass-through between the states. The general conclusion is that the pass-through is stronger in the upper regime periods for Russia.

Figures 8(a)-(h) shows that the pass-through of NEER shock to OIL and NEER is positive in India in the upper regime periods. Although the pass-through to OIL is not noticeable in the first month; however, between the second and third months, the pass-through is positive and insignificant. The pass-through of own shock is positively significant and dampening until it stabilizes to its steady state in the second month. The pass-through to CPI is negative and significant up to the third month, after which it becomes stable. With respect to IPI, the pass-through is initially positive in the first month and later turns negative. However, after the end of the first month, the pass-through to IPI begins to dampen until it becomes stable in the second month. Furthermore, in the lower regime periods, our results demonstrate that the pass-through of NEER to OIL is negative and significant as well as larger compared to the upper regime periods. This remains negative and subsequently stabilizes to its equilibrium value after the fourth month. Concerning the pass-through to CPI, the results provide a positive pass-through initially, and later hits negative within the first month. This pass-through is larger and significant between the first and second months, and hence stabilizes to its equilibrium state in the third month horizon. More so, the pass-through to NEER is positive and significant up to the second month, after which it dampens continuously until its effect becomes neutral after the second month. Finally, the pass-through to IPI is positive in the first month but becomes negative after the first month, and sharply moves towards its steady state in the second month. Furthermore, there is evidence that the pass-through transition for all the variables including own-shocks is instantaneous and the size seems to be only larger in the upper regime periods for NEER and IPI.

The results documented in Figures 9(a)-(h) are pass-through of NEER shocks in China. In the upper regime periods, the pass-through to OIL and IPI is initially negative and become positive but insignificant in the first month. By the end of the first month, it decreases until it becomes stable in the second month. The pass-through to CPI is negative and significant in the first month; this dampens to its equilibrium value in the second month. Lastly, the pass-through to NEER is positive and continue to dampen until it becomes neutral at the end of the first month. This situation of the pass-through is different from the pass-through recorded in the lower regime periods. According to the results, the pass-through of NEER shock to own-variable is positive and hence reaches its steady-state value in the second month. The pass-through to OIL and CPI is negative and significant in the first month. This gradually declines until it becomes neutral in the third month horizon. More so, the pass-through to IPI is negative and significant. It eventually becomes positive after the first month and hence moves to its equilibrium state in the second month horizon. In addition, our results provide that the pass-through transition to its equilibrium value between the states is sharp in all cases both in the upper and lower regime periods except the pass-through to CPI at the lower regime periods, which is characterized by smoothness and slowness.

Finally, figures 10(a)-(h) present the pass-through of NEER shocks for South Africa. In the upper regime periods, the results divulge that the pas-through to OIL, IPI and NEER is positive and only significant in the case of OIL and NEER while it is negative to CPI. The pass-through becomes neutral after the third month for OIL, first month for CPI and second month for IPI. However, the results record that the pass-through to own-variable is positively significant and falling gradually until its impact is extinguished prior to the second month. Likewise, in the lower regime periods, the evidence shows that NEER shocks negatively and significantly pass-through to OIL from first to the second months. For CPI, the pass-through is initially negative, and then crosses to the positive region in the first month. This pass-through stabilizes to its equilibrium value in the second month. The pass-through of own-shocks and IPI is positive. However, for own-shocks, the pass-through continues to decline until it becomes neutral after the first month. In the case of IPI, our evidence provides that the pass-through turns positive within the first month horizon and subsequently drops until it is stabled in the second month horizon. Furthermore, the pass-through transition from the shocks in NEER is apparently instantaneous for South Africa. Also, the size of the pass-through is higher in the upper regime periods compared to the lower regime periods.

4.3.2 Responses to oil price shocks

Similar to the discussions in 4.3.1, the pass-through of OIL shocks to CPI, NEER, IPI and own-variable in the BRICS countries is disclosed both in the upper regime periods and in the lower regime periods. Figures 11(a)-(h) for Brazil indicate that pass-through of OIL shocks to OIL, CPI and IPI is positive and significant within the first month horizon and dampens instantaneously until it becomes negative, after which it gradually stabilizes to its equilibrium value in the tenth month. In the case of CPI, the pass-through becomes significant after the second month and continues to decline smoothly and slowly until it stabilizes to its equilibrium value in twelve months. More so, the pass-through to own-variable is initially negative and significant. It sharply becomes positive and significant within the same month and consequently declines smoothly and slowly until it becomes stable after 15 months. In the lower regime periods, the results provide a positive and significant pass-through of OIL shock to own-variable, CPI and IPI, while the pass-through to NEER is negative and significant until the second month. Furthermore, the results provide evidence of sharp pass-through transition within the first month between the states. In addition, the size of the pass-through is higher in the upper regime periods when the shocks to the transition variable apparently shift the system above the threshold level.

The pass-through of the shocks in OIL with respect to Russia is displayed in Figures 12(a)-(h). In the upper regime periods, the pass-through to OIL, NEER, and IPI is positive and significant, while to CPI is negative and significant. The pass-through becomes neutral after the second month for all the variables except in the case of IPI where it becomes neutral after the first month. In the lower regime periods, the results provide that the pass-through to OIL, NEER, and IPI remains positive and significant. While the pass-through hits its steady state after the first month in the case of OIL to own shocks, the pass-through to NEER and IPI hit negative and subsequently stabilizes to the equilibrium value after the second month. However, the pass-through to NEER and IPI is only significant between the first and second months. More so, the pass-through transition is sharp among the variables. Between first and second month in the upper regime periods, the pass-through to OIL, CPI and NEER is smoother and slower, indicating some delays in stabilizing to the equilibrium values. Comparing the size of the pass-through transition between the states, we find that it is higher in the upper regime periods than in the lower regime periods.

Furthermore, the pass-through of OIL shocks with respect to India are disclosed in Figures 13(a)-(h). In the upper regime periods, the pass-through to OIL itself and CPI is positively and negatively significant and sharp up to the second month, after which the pass-through of the shocks becomes stable. In the case of CPI, the pass-through becomes smoother after the end of the first month until it reaches the equilibrium value. Similarly, the pass-through to NEER and IPI is negative. The pass-through is statistically significant up to the second month for NEER and that of IPI is insignificant after the first month. Whereas, in the lower regime periods, we find evidence that the pass-through to OIL and CPI is positive and negative as well as statistically significant. The pass-through sharply dampen to the steady-state value after the second month. For NEER and IPI, the pass-through is negative and positive; although not statistically significant in the case of NEER. The results further suggest that there is perhaps evidence of a sharp pass-through in India. There is also evidence based on the results that the size of the pass-through transition is higher in the upper regime periods compared to the lower regime periods.

Figures 14(a)-(h) presents the pass-through of the shocks in OIL in China. Based on the results of the upper regime periods, we find a positive and significant pass-through to OIL, CPI and IPI in the first two months. While the pass-through to OIL and CPI sharply dampens in the first month, in the second month, we find evidence of slow and smooth decrease until it gets to the steady state. For IPI, it quickly and drastically declines to its equilibrium value after the first month. More so, the pass-through to NEER is negative, sharp and significant up to the end of the first month after which it becomes neutral. In the lower regime periods, the pass-through to the OIL, CPI, and IPI is positive, and statistically significant in the first month. The impact is sharp and become neutral after the first month. For NEER, the pass-through is negative and significant in the first month. This pass-through continues to dampen smoothly and gradually until it becomes stable after the second month. Furthermore, the results suggest that the pass-through transition in China is mostly instantaneous in nature except in the case of pass-through to NEER in the lower regime where it is smoother and slower.

In South Africa, the results of the pass-through of OIL shocks are displayed in Figures 15(a)-(h). In the upper regime periods, the OIL shocks positively and significantly pass-through to itself. The pass-through of NEER and IPI is positive and significant while the pass-through to CPI is negative and statistically significant in the first month. The results further suggest that the pass-through converge to the equilibrium value sharply after the second month in the cases of OIL and CPI. However, for NEER, the pass-through declines and hits negative after the first month and then sharply decreases to the equilibrium in the second month. For IPI, the pass-through becomes neutral after the first month. Furthermore, in the lower regime periods, the pass-through to itself is positive and significant. Equally, the pass-through to NEER and IPI is positive and significant in the first month. The pass-through converges to the stable state after the second month. In the case of the pass-through to CPI, we find it to be negative and significant. The results show that the pass-through sharply approaches the steady state after the second month. In the case of pass-through to CPI, we find a delay after the end of the first month. Similarly, in the lower regime periods for the pass-through to OIL itself, and to NEER, there is a delay in the second month until it gradually stabilizes to its equilibrium state.

5. Conclusions

Several studies have come to the limelight in the literature of asymmetric EROPPT in recent times. However, a common limitation of the literature is that many of these studies focus mostly on the direction of the pass-through and the role of inflation volatility in the channel of pass-through without giving due consideration to whether the state of the economy in exchange rate and oil price matter for pass-through. This leaves a missing gap in the literature. This paper, therefore, investigates not only the question of the asymmetric EROPPT to inflation but also to investigate the extent to which the size of the shocks to exchange rate and oil price affect such asymmetric relationship in the BRICS countries. To achieve this objective, we apply the nonlinear VSTAR model, which allows a smooth transition, governed by the selected transition variables to determine the pass-through in the upper and lower regime periods.

The results of the linearity tests based on the LM, LR, and F_{RAO} versions of linearity tests indicate the presence of nonlinearity in all the equations in each of the country. The results based on the model estimations show that the variables asymmetrically respond to the shocks in all the equations in the upper and lower regime periods. To interpret the dynamics of the pass-through, we make use of the GIRFs, which we obtained with 1000 bootstrap repetitions. The results show evidence asymmetric and significant of EROPPT in the upper and lower regime periods. The results also divulge the presence of asymmetric pass-through in all the countries with strong evidence of higher pass-through when the size of the shocks to the transition variable crosses some threshold level. Furthermore, our results provide that output growth asymmetrically react to the large and small shocks to exchange rate and oil price differently. The implication for these results is that state of the economy matter for the EROPPT. Therefore, a sound macroeconomic management is required to reduce the pass-through effect especially when exchange rate and oil price fluctuations are above a certain threshold.

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Table 1: Descriptive Statistics

Country	Variable	Obs.	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis	JB	Prob.
Brazil	***Panel A: Log levels***										
	LCPI	388	1.018997	4.075663	5.070877	-16.57065	6.396228	-1.691848	4.378926	215.8384	0.000000
	LIPI	388	4.360285	4.340856	4.661645	3.854554	0.171673	-0.053943	1.940456	18.33742	0.000104
	LNEER	388	7.669047	4.579227	24.15897	3.989513	6.045022	1.680257	4.300968	209.9333	0.000000
	LOILPRICE	388	1.029656	4.217415	5.526531	-16.65770	6.514840	-1.616267	4.168795	191.0150	0.000000
	Panel B: Log growth rate (%)										
	CPI	387	5.592126	0.618144	60.09785	-0.511013	10.22331	2.265599	8.301609	784.3009	0.000000
	IPI	387	0.088113	0.014175	25.04676	-28.65762	3.830480	-0.203315	15.53172	2535.002	0.000000
	NEER	387	-5.171851	-0.991641	23.24798	-48.75259	10.78120	-1.581341	5.248093	242.7857	0.000000
	OILPRICE	387	5.567258	3.911372	59.28725	-33.03097	13.61654	0.791329	4.517514	77.52346	0.000000
Russia	***Panel A: Log levels***										
	LCPI	280	3.994640	4.218929	5.145201	1.426907	0.951375	-0.855137	2.711300	35.09782	0.000000
	LIPI	280	4.478483	4.529146	4.774316	4.041075	0.220185	-0.343405	1.569245	29.38564	0.000000
	LNEER	280	4.781331	4.682733	6.000754	3.983573	0.493661	1.227443	3.707925	76.15559	0.000000
	LOILPRICE	280	6.994150	7.416477	8.320565	4.279885	1.186111	-1.073785	2.860546	54.03423	0.000000
	Panel B: Log growth rate (%)										
	CPI	279	1.332722	0.796805	32.51945	-0.541475	2.431510	8.427774	100.4034	113594.1	0.000000
	IPI	279	0.148411	0.278738	36.87810	-36.37963	3.916431	0.121407	56.82635	33681.52	0.000000
	NEER	279	-0.706954	-0.110797	12.84716	-75.22282	5.555069	-8.961018	118.0875	157708.5	0.000000
	OILPRICE	279	1.448272	1.415102	81.86996	-26.96859	9.186072	2.147879	23.31527	5012.278	0.000000
India	***Panel A: Log levels***										
	LCPI	388	4.026699	4.053521	5.124215	2.788211	0.666429	-0.096055	1.975092	17.57872	0.000152
	LIPI	388	3.958581	3.895726	4.972909	2.913711	0.583388	0.007951	1.695562	27.51264	0.000001
	LNEER	388	4.807077	4.754699	5.790924	4.259280	0.364154	0.836282	3.081124	45.33218	0.000000
	LOILPRICE	388	7.157390	7.196706	8.867119	4.984887	1.027749	-0.191852	1.822644	24.78992	0.000004
	Panel B: Log growth rate (%)										
	CPI	387	0.596989	0.621764	4.473589	-4.207775	0.866835	-0.328521	6.519883	206.7432	0.000000
	IPI	387	0.528334	0.467177	20.19156	-11.33461	2.624107	0.881922	14.31522	2114.719	0.000000
	NEER	387	-0.380438	-0.263247	6.334198	-19.31782	1.989631	-3.991808	38.19138	20997.51	0.000000
	OILPRICE	387	0.710185	1.231999	40.94007	-41.07009	8.864054	-0.349374	5.910145	144.4348	0.000000

China	***Panel A: Log levels***									
	LCPI	340	4.644574	4.627910	4.849684	4.582925	0.052615	2.027565	7.027911	462.7988	0.000000
	LIPI	340	4.719602	4.718006	4.868343	4.385381	0.047909	-0.682358	9.265864	582.5829	0.000000
	LNEER	340	4.583393	4.586730	4.881276	4.211068	0.154223	-0.353737	2.610152	9.243750	0.009834
	LOILPRICE	340	5.696524	5.615523	6.951132	4.476394	0.644509	0.140261	1.672392	26.08417	0.000002
	Panel B: Log growth rate (%)									
	CPI	339	-0.007157	0.000000	2.245092	-2.607971	0.700642	-0.109977	4.171660	20.07399	0.000044
	IPI	339	0.085124	0.024691	24.82882	-23.85232	3.724733	0.022520	17.63733	3026.329	0.000000
	NEER	339	-0.018894	0.135452	5.899195	-39.70609	2.499935	-11.81161	188.7983	495491.7	0.000000
	OILPRICE	339	0.315347	1.147736	39.15444	-33.18515	8.502249	-0.313888	5.155114	71.17049	0.000000
S. Africa	***Panel A: Log levels***									
	LCPI	340	4.240805	4.293636	5.020643	3.176699	0.484056	-0.299998	2.173486	14.77755	0.000618
	LIPI	340	4.491540	4.505920	4.705532	4.176192	0.118836	-0.535070	2.226985	24.68897	0.000004
	LNEER	340	4.782962	4.760198	5.590149	3.945015	0.438962	0.149618	2.001726	15.38632	0.000456
	LOILPRICE	340	5.513011	5.631227	7.022546	3.793362	1.006921	-0.227718	1.554696	32.53128	0.000000
	Panel B: Log growth rate (%)									
	CPI	339	0.543936	0.478470	2.666847	-1.141886	0.499469	0.594338	4.194314	40.10560	0.000000
	IPI	339	0.079609	-0.018259	9.690183	-9.609447	2.329628	-0.057542	5.561979	92.89985	0.000000
	NEER	339	-0.416090	-0.303963	8.894686	-17.64327	2.986058	-1.146915	8.462187	495.7471	0.000000
	OILPRICE	339	0.780077	0.967010	38.57859	-41.74234	8.738280	-0.350976	5.382956	87.16842	0.000000

Notes: The table summarizes descriptive statistics, which contains the sample mean, median, maximum, minimum, standard deviation, skewness, kurtosis, Jarque–Bera (JB) test statistic, and the p-value of the Jarque–Bera test statistic. The variables used include CPI, IPI, NEER and Oil price in the national currency of each of the BRICS countries. Panel A summarizes the log levels and Panel B summarizes the log growth rate (%).

Table 2: Linearity Tests

A) Brazil

		Transition variable			
Hypothesis: Statistics	**Equation**	**OIL_{t-1}**	**CPI_{t-1}**	**$NEER_{t-1}$**	**IPI_{t-1}**
H_{01}: F	OIL	0.222	9.443	6.645	5.288
H_{01}: F	CPI	3.315	45.173***	18.296***	24.864***
H_{01}: F	NEER	2.079*	8.379***	7.448***	9.675***
H_{01}: F	IPI	1.270^{+}	14.996***	9.094***	13.475***
H_{02}: F	OIL	3.474	2.493***	2.878***	0.795***
H_{02}: F	CPI	1.604**	15.636*	19.129*	6.934
H_{02}: F	NEER	3.497	1.200***	17.685***	3.750***
H_{02}: F	IPI	1.869**	9.362	8.785***	4.140**
H_{03}: F	OIL	1.187	1.868***	0.464***	1.394**
H_{03}: F	CPI	15.623	15.948	13.245	0.228
H_{03}: F	NEER	3.804***	3.743***	1.922***	4.844
H_{03}: F	IPI	3.232**	1.421**	3.595	2.472***
H_{01}: LR	System	30.990*	194.520	118.010**	141.078*
H_{02}: LR	System	83.209*	75.653***	82.236***	36.320***
H_{03}: LR	System	83.209***	75.653***	82.236***	36.320**

B) Russia

		Transition variable			
Hypothesis: Statistics	**Equation**	**OIL_{t-1}**	**CPI_{t-1}**	**$NEER_{t-1}$**	**IPI_{t-1}**
H_{01}: F	OIL	3.261	3.732	2.384	1.577
H_{01}: F	CPI	17.962*	20.099**	20.045^{+}	9.700
H_{01}: F	NEER	5.806***	6.122***	6.051***	2.722***
H_{01}: F	IPI	8.302***	0.807***	14.585***	19.242*
H_{02}: F	OIL	3.042***	2.238	1.088***	5.051***
H_{02}: F	CPI	5.637*	0.420^{+}	2.737	3.143***
H_{02}: F	NEER	5.687***	1.480	3.300*	4.172*
H_{02}: F	IPI	3.126***	1.351	4.108*	1.764**
H_{03}: F	OIL	2.800*	1.740	0.726**	0.800
H_{03}: F	CPI	4.432*	11.221	1.867	1.276
H_{03}: F	NEER	6.119**	9.258***	3.067	1.252
H_{03}: F	IPI	4.501***	0.437***	0.507*	0.944
H_{01}: LR	System	131.262**	103.346	155.340	134.293
H_{02}: LR	System	43.630***	54.952***	19.017***	18.669***
H_{03}: LR	System	43.630***	54.952***	19.017	18.669

C) India

Hypothesis: Statistics	Equation	*Transition variable* OIL_{t-1}	CPI_{t-1}	$NEER_{t-1}$	IPI_{t-1}
H_{01}: F	OIL	2.741	0.222	2.156	0.913
H_{01}: F	CPI	0.745^{*}	0.987	1.250^{+}	0.536
H_{01}: F	NEER	11.128	1.518	1.076	4.585
H_{01}: F	IPI	2.027^{***}	0.686	1.325	1.920^{**}
H_{02}: F	OIL	1.517^{+}	0.273	0.468	0.880
H_{02}: F	CPI	1.231	7.642	0.791	1.362
H_{02}: F	NEER	11.152	0.427^{***}	1.199	1.797
H_{02}: F	IPI	0.803^{***}	1.761	0.809	6.156
H_{03}: F	OIL	2.221	0.535	0.797	0.415^{***}
H_{03}: F	CPI	1.493^{+}	4.417	0.974	2.672
H_{03}: F	NEER	9.210	1.428^{**}	0.741	1.152^{*}
H_{03}: F	IPI	1.762^{***}	0.908	0.587	12.192
H_{01}: LR	System	63.557	13.895	22.415	33.254^{***}
H_{02}: LR	System	55.188^{***}	29.200	12.790	64.612^{**}
H_{03}: LR	System	55.188^{***}	29.200^{*}	12.790	64.612^{***}

D) China

Hypothesis: Statistics	Equation	*Transition variable* OIL_{t-1}	CPI_{t-1}	$NEER_{t-1}$	IPI_{t-1}
H_{01}: F	OIL	1.938	0.555	1.931	0.523
H_{01}: F	CPI	0.745	0.337	0.163	0.687
H_{01}: F	NEER	12.066	13.994	2.290	6.501
H_{01}: F	IPI	6.150^{***}	9.354^{***}	10.057^{+}	10.054^{***}
H_{02}: F	OIL	2.873^{***}	1.305^{***}	4.406^{***}	2.476^{***}
H_{02}: F	CPI	0.267^{*}	2.385	1.221^{**}	3.008^{*}
H_{02}: F	NEER	0.333	14.031^{+}	0.486	6.276^{*}
H_{02}: F	IPI	0.643	3.079^{***}	2.660	3.074^{***}
H_{03}: F	OIL	0.460	4.014^{*}	1.808^{*}	3.385^{*}
H_{03}: F	CPI	2.975	1.990^{**}	2.073	2.310^{**}
H_{03}: F	NEER	7.004^{*}	9.027^{+}	2.422^{+}	4.518^{+}
H_{03}: F	IPI	4.416^{***}	0.176^{***}	4.780^{*}	6.752^{**}
H_{01}: LR	System	75.920^{**}	86.243	51.859^{***}	61.691^{***}
H_{02}: LR	System	53.989^{***}	53.459^{***}	42.493^{***}	65.184^{***}
H_{03}: LR	System	53.989^{***}	53.459^{***}	42.493^{***}	65.184^{***}

E) South Africa

Hypothesis: Statistics	Equation	Transition variable			
		OIL$_{t-1}$	**CPI$_{t-1}$**	**NEER$_{t-1}$**	**IPI$_{t-1}$**
H_{01}: F	OIL	1.832	1.609	0.940	0.435
H_{01}: F	CPI	0.571	1.300	0.335	0.334
H_{01}: F	NEER	0.912	0.820	2.149	0.890
H_{01}: F	IPI	2.391	1.463	1.852^{+}	3.651
H_{02}: F	OIL	2.410^{+}	0.727	1.948	0.683**
H_{02}: F	CPI	0.818*	5.824	0.800	0.634
H_{02}: F	NEER	1.199	0.669***	0.905	0.275
H_{02}: F	IPI	0.983	0.589	0.416	1.967
H_{03}: F	OIL	2.125	0.331	0.496	1.550^{+}
H_{03}: F	CPI	1.615^{+}	0.423	2.602	0.977
H_{03}: F	NEER	0.644	0.132	0.858*	1.024
H_{03}: F	IPI	0.879	0.571	4.219	1.046
H_{01}: LR	System	22.692	20.208	20.642**	20.413
H_{02}: LR	System	19.076	6.390	31.796	16.896
H_{03}: LR	System	19.076	6.390	31.796*	16.896

Note: $^{+}$, *, **, and *** denote significance at 10%, 5%, 1%, and 0.1%, respectively.

Table 3a: Estimates of VSTAR model for Brazil

Parameter	System	Equation			
		OIL	**CPI**	**NEER**	**IPI**
c	22.340***				
	(1.805)				
γ	22.628**				
	(8.203)				
μ_i^1		0.339	0.004	0.317	0.216
		(0.602)	(0.186)	(0.302)	(0.208)
$\phi_{1,OIL}^1$		0.137*	0.031	-0.080*	0.040^{+}
		(0.064)	(0.020)	(0.032)	(0.022)
$\phi_{1,CPI}^1$		1.050***	1.001***	-0.798***	0.099^{+}
		(0.146)	(0.045)	(0.073)	(0.050)
$\phi_{1,NEER}^1$		0.228^{+}	-0.018	0.123*	0.120**
		(0.119)	(0.037)	(0.060)	(0.041)
$\phi_{1,IPI}^1$		0.184	0.107*	0.036	-0.400***
		(0.141)	(0.044)	(0.071)	(0.049)
μ_i^2		0.561	-4.879*	-1.384	0.630
		(6.194)	(1.918)	(3.105)	(2.135)
$\phi_{1,OIL}^1$		0.168	0.203**	-0.124	0.050
		(0.205)	(0.064)	(0.103)	(0.071)
$\phi_{1,CPI}^1$		-0.318	-0.349***	0.469**	-0.309**
		(0.290)	(0.090)	(0.145)	(0.100)
$\phi_{1,NEER}^1$		-0.018	-0.165	0.218	-0.131
		(0.353)	(0.109)	(0.177)	(0.122)
$\phi_{1,IPI}^1$		1.559**	0.743***	-0.710**	0.492**
		(0.478)	(0.148)	(0.240)	(0.165)
F linearity test		3.625**	12.894***	6.727***	6.068***
		(0.000)	(0.000)	(0.000)	(0.000)
LR linearity test	75.463***				
F_{RAO} linearity test	3.876***				

Note: $^{+}$, *, **, and *** denote significance at 10%, 5%, 1%, and 0.1%, respectively.

Table 3b: Estimates of VSTAR model for Russia

Parameter	System	*Equation* OIL	CPI	NEER	IPI
c	1.370				
	(390.240)				
γ	15.000				
	(3415.923)				
μ_i^1		1.609	-0.032	-0.134	0.300
		(1.349)	(0.304)	(0.783)	(0.485)
$\phi_{1,OIL}^1$		0.303^{+}	-0.016	0.008	0.118^{*}
		(0.154)	(0.035)	(0.090)	(0.056)
$\phi_{1,CPI}^1$		0.165	0.901^{***}	0.163	0.296
		(0.596)	(0.135)	(0.346)	(0.215)
$\phi_{1,NEER}^1$		-0.249	-0.057	0.538^{***}	-0.020
		(0.230)	(0.052)	(0.133)	(0.083)
$\phi_{1,IPI}^1$		0.082	0.009	0.102	-0.056
		(0.204)	(0.046)	(0.118)	(0.073)
μ_i^2		-1.157	0.712	-0.274	-0.349
		(2.136)	(0.482)	(1.240)	(0.769)
$\phi_{1,OIL}^1$		-0.102	0.010	-0.119	-0.026
		(0.223)	(0.050)	(0.129)	(0.080)
$\phi_{1,CPI}^1$		0.278	-0.260	0.035	-0.620^{*}
		(0.857)	(0.193)	(0.497)	(0.308)
$\phi_{1,NEER}^1$		0.607^{+}	0.213^{**}	-0.321	-0.028
		(0.355)	(0.080)	(0.206)	(0.128)
$\phi_{1,IPI}^1$		-0.061	-0.057	-0.083	-0.719^{***}
		(0.295)	(0.067)	(0.171)	(0.106)
F linearity test		1.411	7.878^{***}	2.245^{+}	12.832^{***}
		(0.000)	(0.000)	(0.000)	(0.000)
LR linearity test	107.304^{***}				
F_{RAO} linearity test	5.674^{***}				

Note: $^{+}$, *, **, and *** denote significance at 10%, 5%, 1%, and 0.1%, respectively.

Table 3c: Estimates of VSTAR model for India

Parameter	System	*Equation* OIL	CPI	NEER	IPI
c	2.514^{***}				
	(0.163)				
γ	11.900				
	(120.475)				
μ_i^1		0.843	0.419^{***}	-0.017	0.645^{***}
		(0.621)	(0.048)	(0.134)	(0.172)
$\phi_{1,OIL}^1$		0.279^{***}	-0.002	-0.018	-0.005
		(0.053)	(0.004)	(0.011)	(0.015)
$\phi_{1,CPI}^1$		-0.227	0.245^{***}	-0.359^{*}	0.090
		(0.704)	(0.055)	(0.152)	(0.195)
$\phi_{1,NEER}^1$		0.057	-0.010	0.166^{***}	-0.085
		(0.229)	(0.018)	(0.049)	(0.063)
$\phi_{1,IPI}^1$		0.009	-0.031	0.050	-0.506^{***}
		(0.250)	(0.019)	(0.054)	(0.069)
μ_i^2		1.353	0.459^{+}	-1.010	-0.313
		(3.007)	(0.234)	(0.650)	(0.833)

$\phi^{1}_{1,OIL}$		-0.344*	0.025*	-0.223***	0.042
		(0.158)	(0.012)	(0.034)	(0.044)
$\phi^{1}_{1,CPI}$		-1.067	-0.035	0.145	1.148*
		(1.899)	(0.148)	(0.411)	(0.526)
$\phi^{1}_{1,NEER}$		-1.226	0.089	-0.367*	0.098
		(0.855)	(0.066)	(0.185)	(0.237)
$\phi^{1}_{1,IPI}$		-0.179	-0.034	0.128	-0.038
		(0.497)	(0.039)	(0.107)	(0.138)
F linearity test		1.151	2.287^{+}	6.837***	1.899
		(0.000)	(0.000)	(0.000)	(0.000)
LR linearity test	48.505***				
F_{RAO} linearity test	2.464***				

Note: $^{+}$, *, **, and *** denote significance at 10%, 5%, 1%, and 0.1%, respectively.

Table 3d: Estimates of VSTAR model for China

		Equation			
Parameter	**System**	**OIL**	**CPI**	**NEER**	**IPI**
c	5.066***				
	(1.117)				
γ	7.774*				
	(2.523)				
μ^{1}_{i}		0.162	-0.013	0.049	0.182
		(0.463)	(0.037)	(0.108)	(0.159)
$\phi^{1}_{1,OIL}$		0.282***	0.003	-0.009	0.021
		(0.055)	(0.004)	(0.013)	(0.019)
$\phi^{1}_{1,CPI}$		0.706	0.264***	-0.194	0.233
		(0.721)	(0.058)	(0.168)	(0.248)
$\phi^{1}_{1,NEER}$		-0.614^{+}	-0.046	0.418***	-0.196
		(0.367)	(0.030)	(0.085)	(0.126)
$\phi^{1}_{1,IPI}$		-0.294^{+}	0.047***	-0.001	-0.400***
		(0.171)	(0.014)	(0.040)	(0.059)
μ^{2}_{i}		7.579	1.366**	-12.146***	-3.710*
		(5.319)	(0.429)	(1.237)	(1.831)
$\phi^{1}_{1,OIL}$		0.059	-0.040^{+}	0.586***	0.029
		(0.298)	(0.024)	(0.069)	(0.103)
$\phi^{1}_{1,CPI}$		0.158	-0.051	-3.426***	2.599***
		(2.247)	(0.181)	(0.523)	(0.774)
$\phi^{1}_{1,NEER}$		2.008^{+}	0.080	-1.383***	1.826***
		(1.032)	(0.083)	(0.240)	(0.355)
$\phi^{1}_{1,IPI}$		-0.390	-0.123**	0.790***	0.334*
		(0.476)	(0.038)	(0.111)	(0.164)
F linearity test		1.629	3.294*	33.525***	13.042***
		(0.000)	(0.000)	(0.000)	(0.000)
LR linearity test	166.770***				
F_{RAO} linearity test	8.974***				

Note: $^{+}$, *, **, and *** denote significance at 10%, 5%, 1%, and 0.1%, respectively.

Table 3e: Estimates of VSTAR model for South Africa

Parameter	System	*Equation* OIL	CPI	NEER	IPI
c	1.383				
	(1.208)				
γ	4.244				
	(2.416)				
μ_i^1		2.632^{*}	0.284^{***}	-0.578	0.080
		(1.155)	(0.047)	(0.387)	(0.279)
$\phi_{1,OIL}^1$		0.159^{*}	0.005^{+}	-0.010	0.031^{+}
		(0.068)	(0.003)	(0.023)	(0.016)
$\phi_{1,CPI}^1$		-1.341	0.564^{***}	-0.100	-0.693^{*}
		(1.386)	(0.056)	(0.465)	(0.335)
$\phi_{1,NEER}^1$		0.484^{+}	-0.005	0.157^{+}	-0.056
		(0.252)	(0.010)	(0.085)	(0.061)
$\phi_{1,IPI}^1$		-0.115	0.009	0.005	-0.396^{***}
		(0.257)	(0.010)	(0.086)	(0.062)
μ_i^2		-6.030	-0.235	-0.050	1.967^{*}
		(3.712)	(0.150)	(1.246)	(0.896)
$\phi_{1,OIL}^1$		-0.013	0.001	0.000	-0.042
		(0.173)	(0.007)	(0.058)	(0.042)
$\phi_{1,CPI}^1$		-1.004	-0.085	1.707	0.870
		(3.114)	(0.126)	(1.045)	(0.752)
$\phi_{1,NEER}^1$		1.042	0.027	0.124	-0.424^{*}
		(0.728)	(0.029)	(0.244)	(0.176)
$\phi_{1,IPI}^1$		1.083	0.002	-0.101	-0.158
		(0.717)	(0.029)	(0.240)	(0.173)
F linearity test		1.571	1.335	1.916	2.458^{*}
		(0.000)	(0.000)	(0.000)	(0.000)
LR linearity test	28.648^{*}				
F_{RAO} linearity test	1.446^{+}				

Note: $^{+}$, *, **, and *** denote significance at 10%, 5%, 1%, and 0.1%, respectively.

Figure 1: Time series plot of data in levels for Brazil

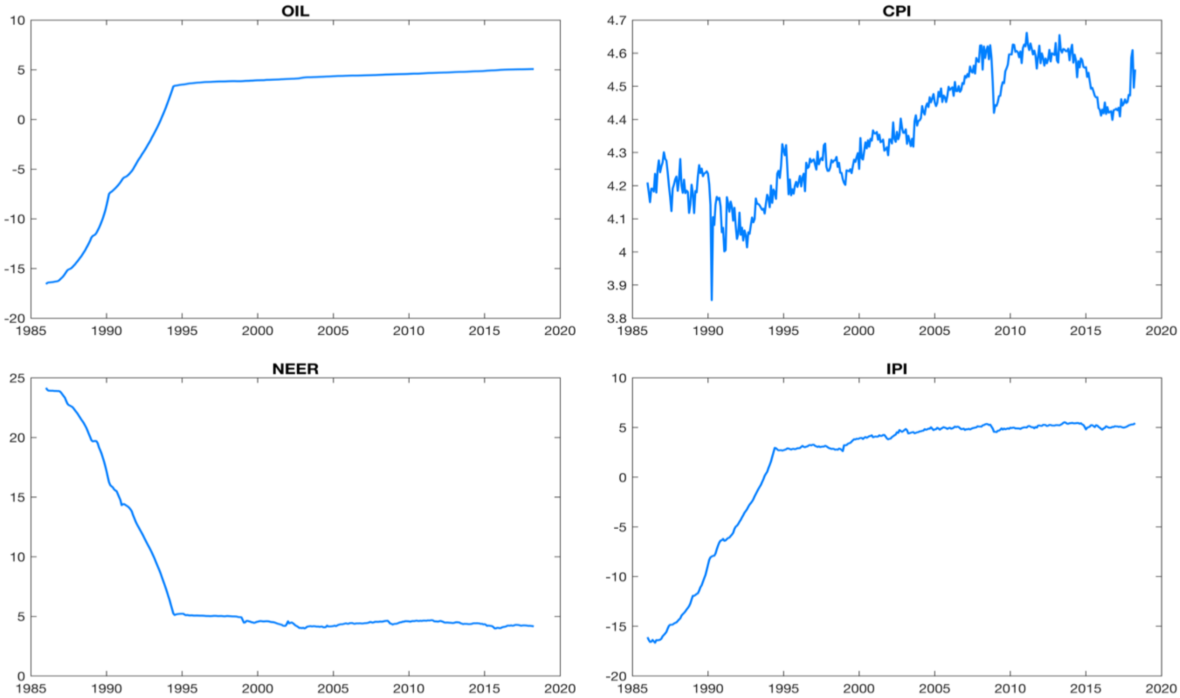


Figure 2: Time series plot of data in levels for Russia

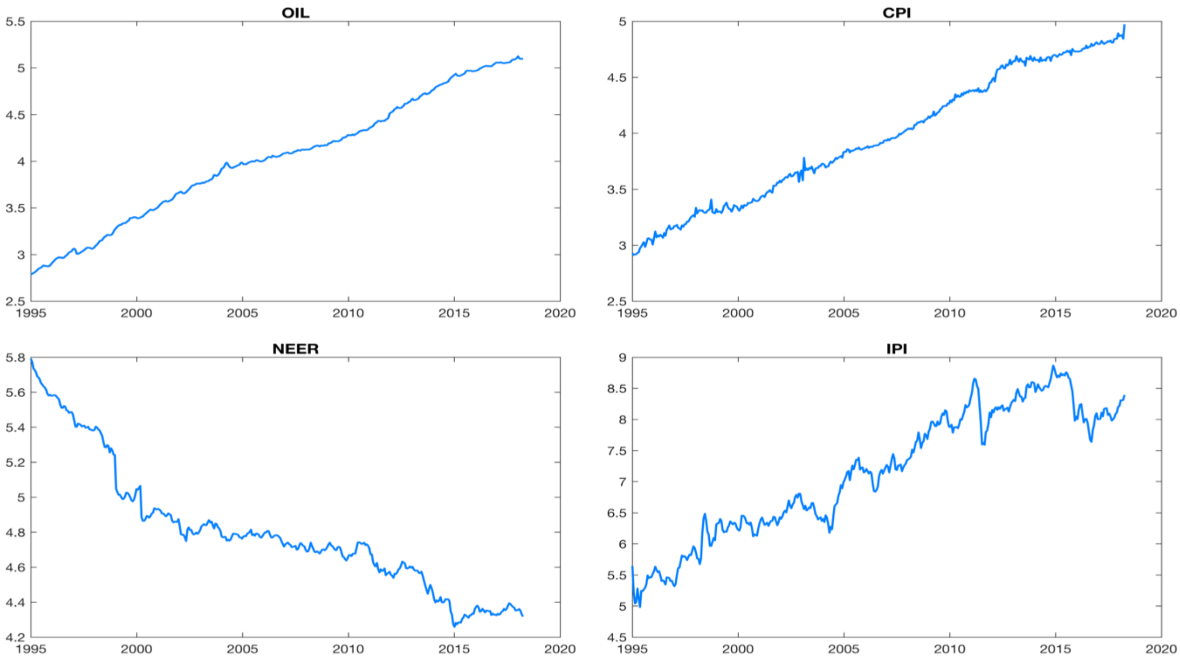


Figure 3: Time series plot of data in levels for India

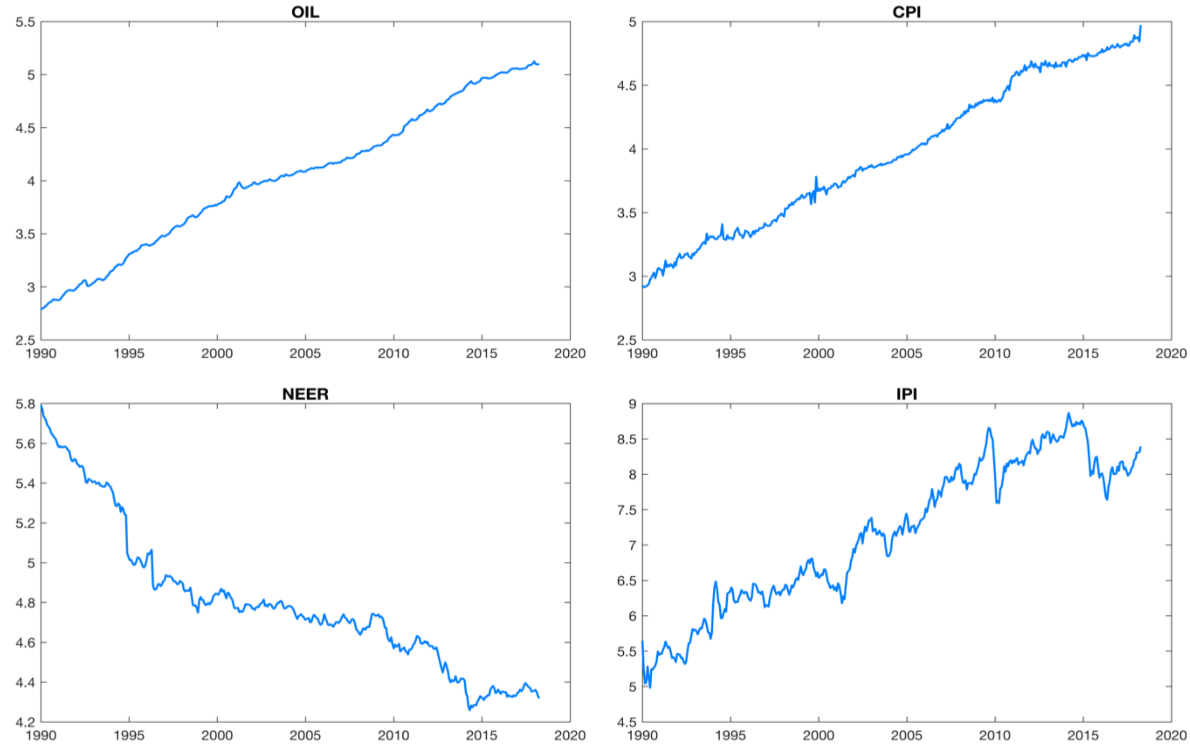


Figure 4: Time series plot of data in levels for China

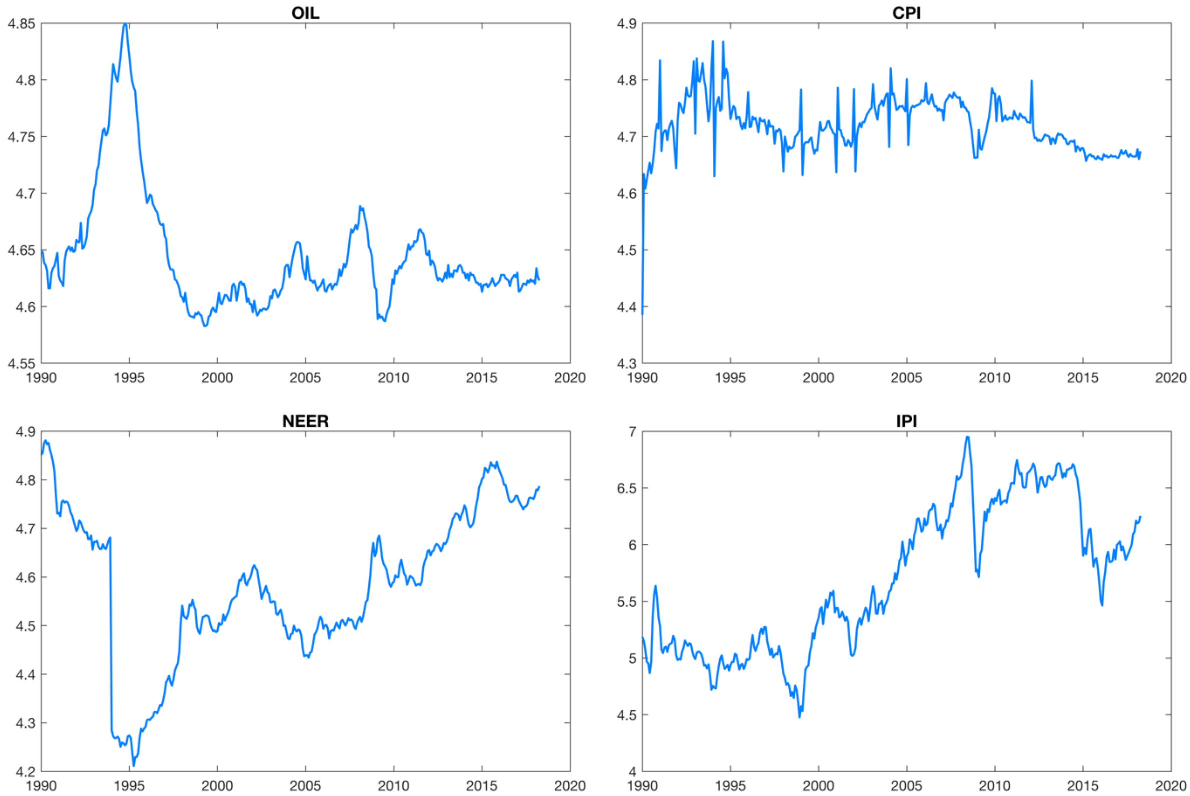


Figure 5: Time series plot of data in levels for South Africa

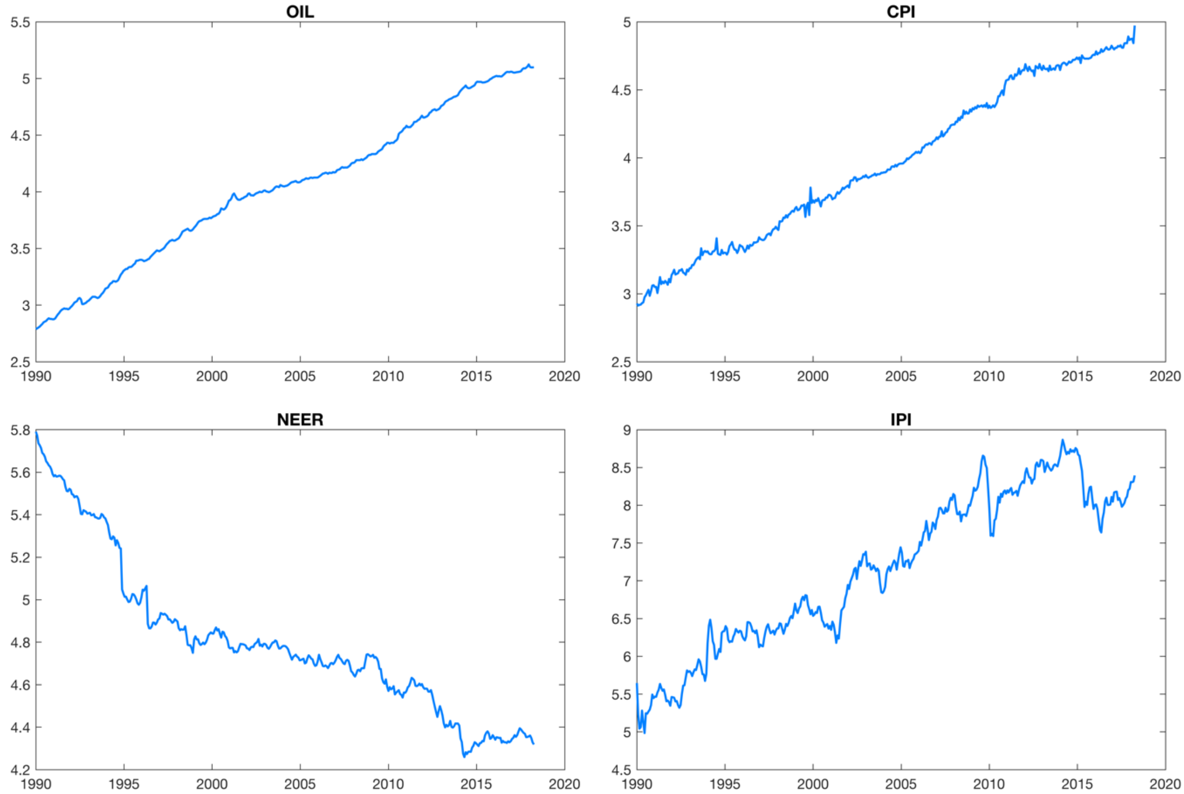
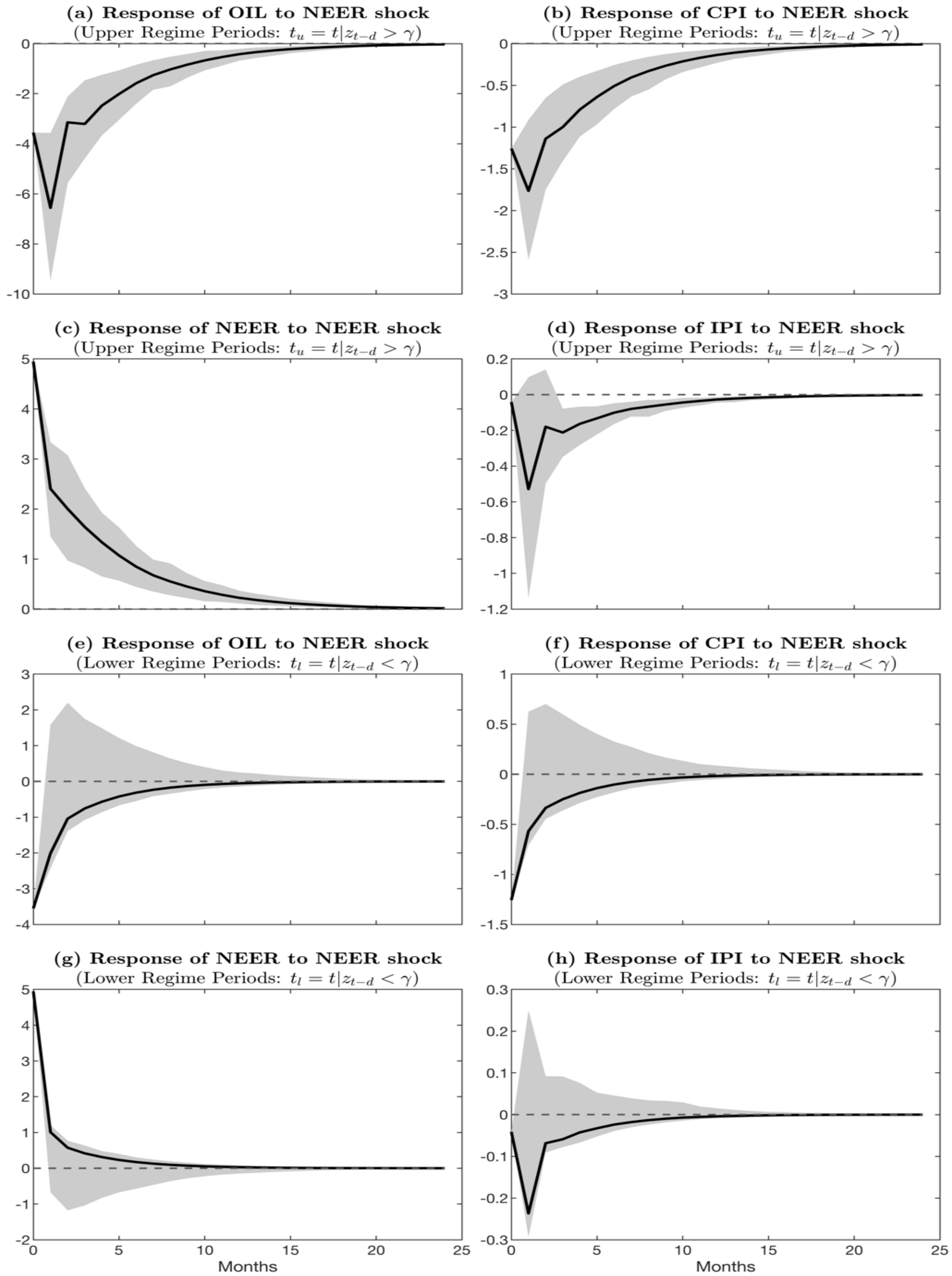
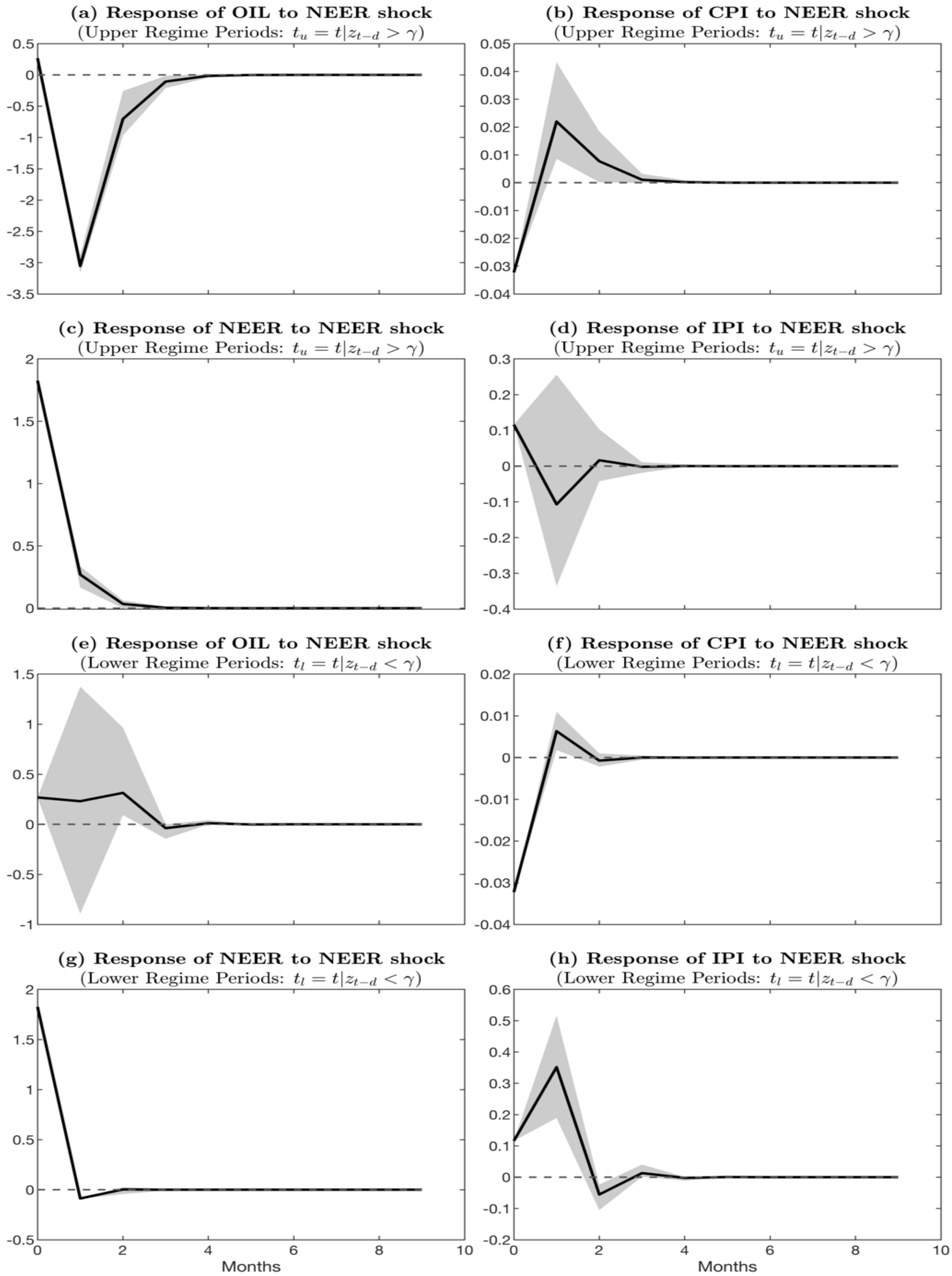


Figure 6: Responses to exchange rate shocks for Brazil



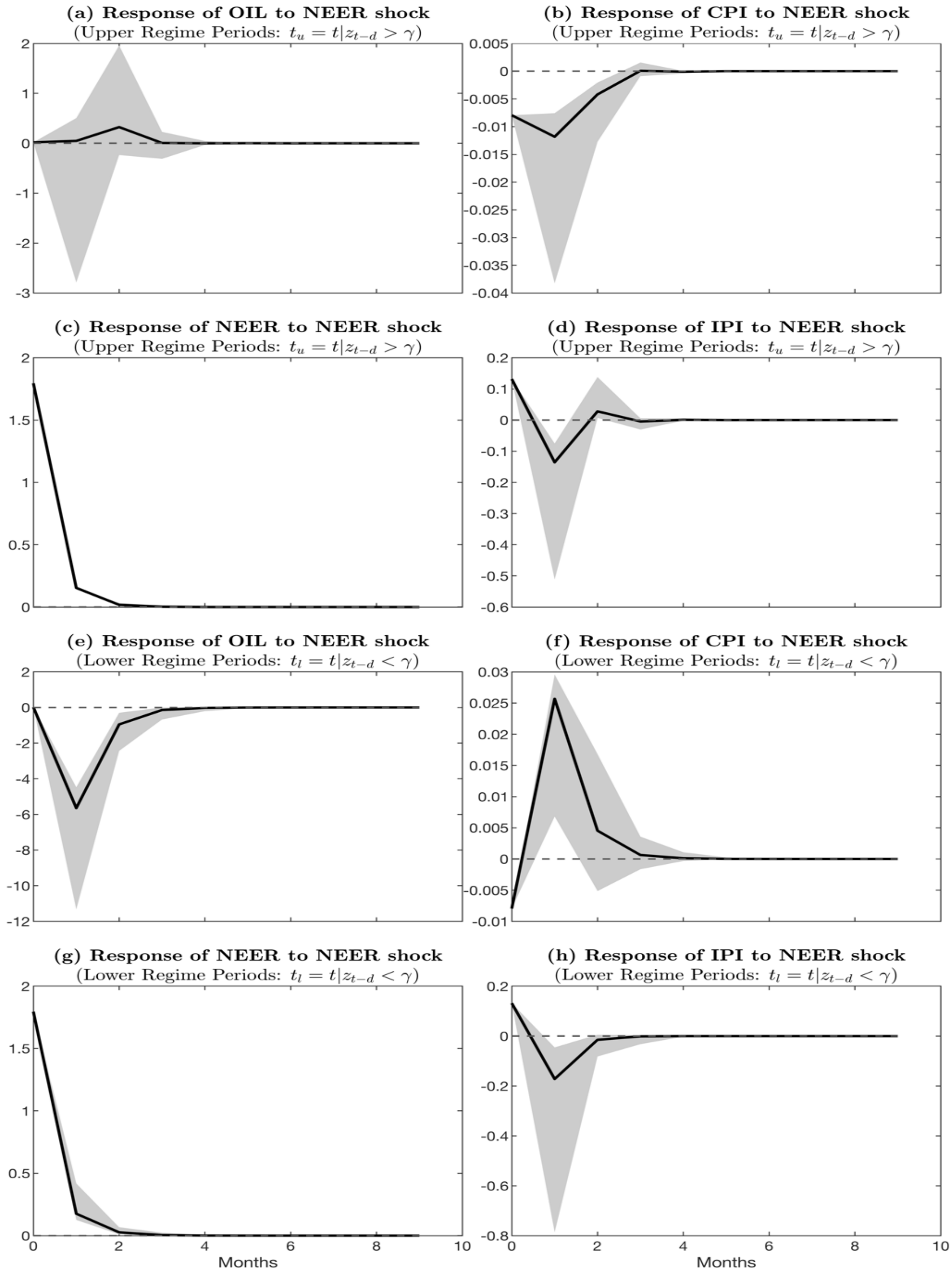
Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.

Figure 7: Responses to exchange rate shocks for Russia



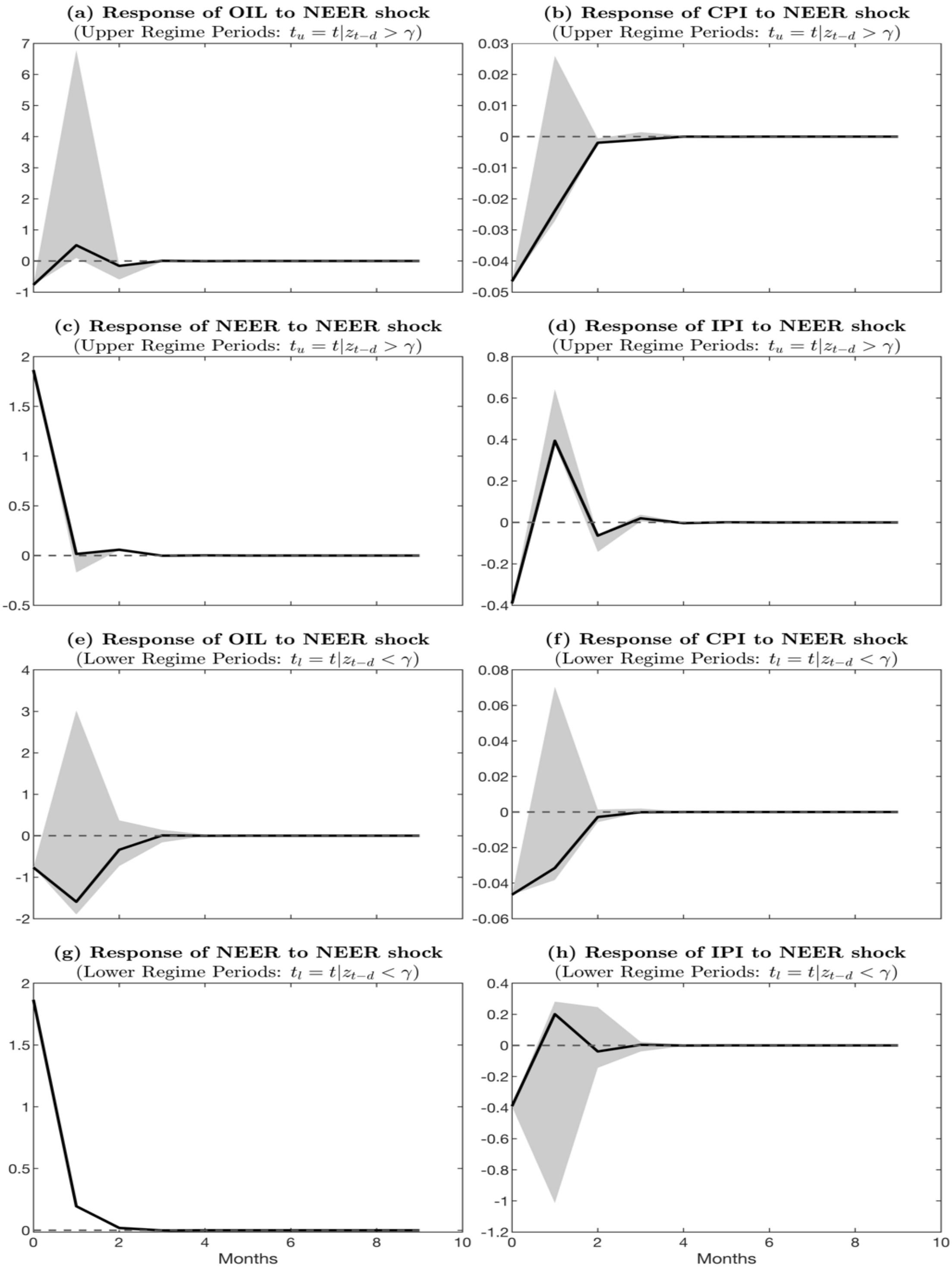
Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.

Figure 8: Responses to exchange rate shocks for India



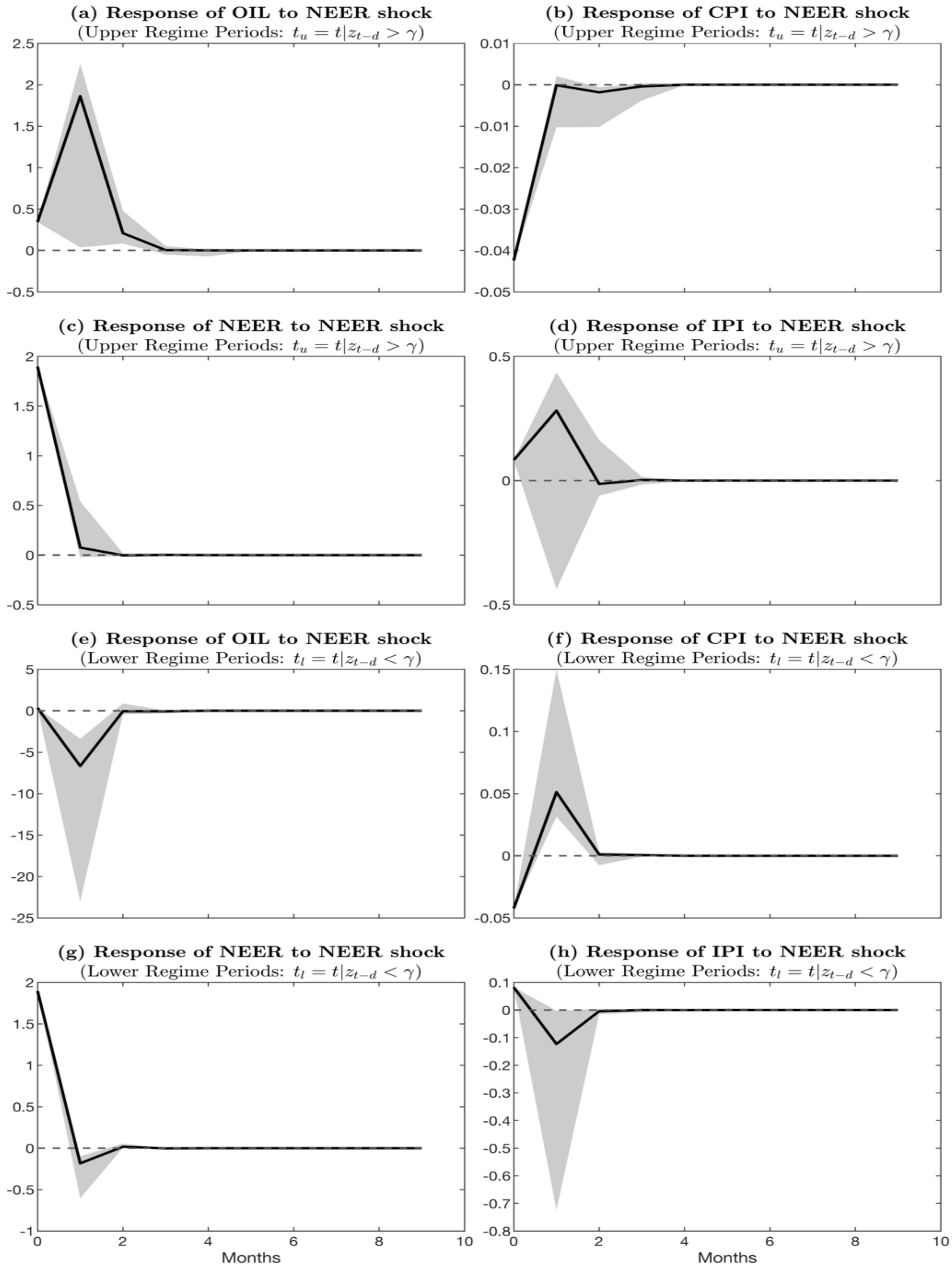
Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.

Figure 9: Responses to exchange rate shocks for China



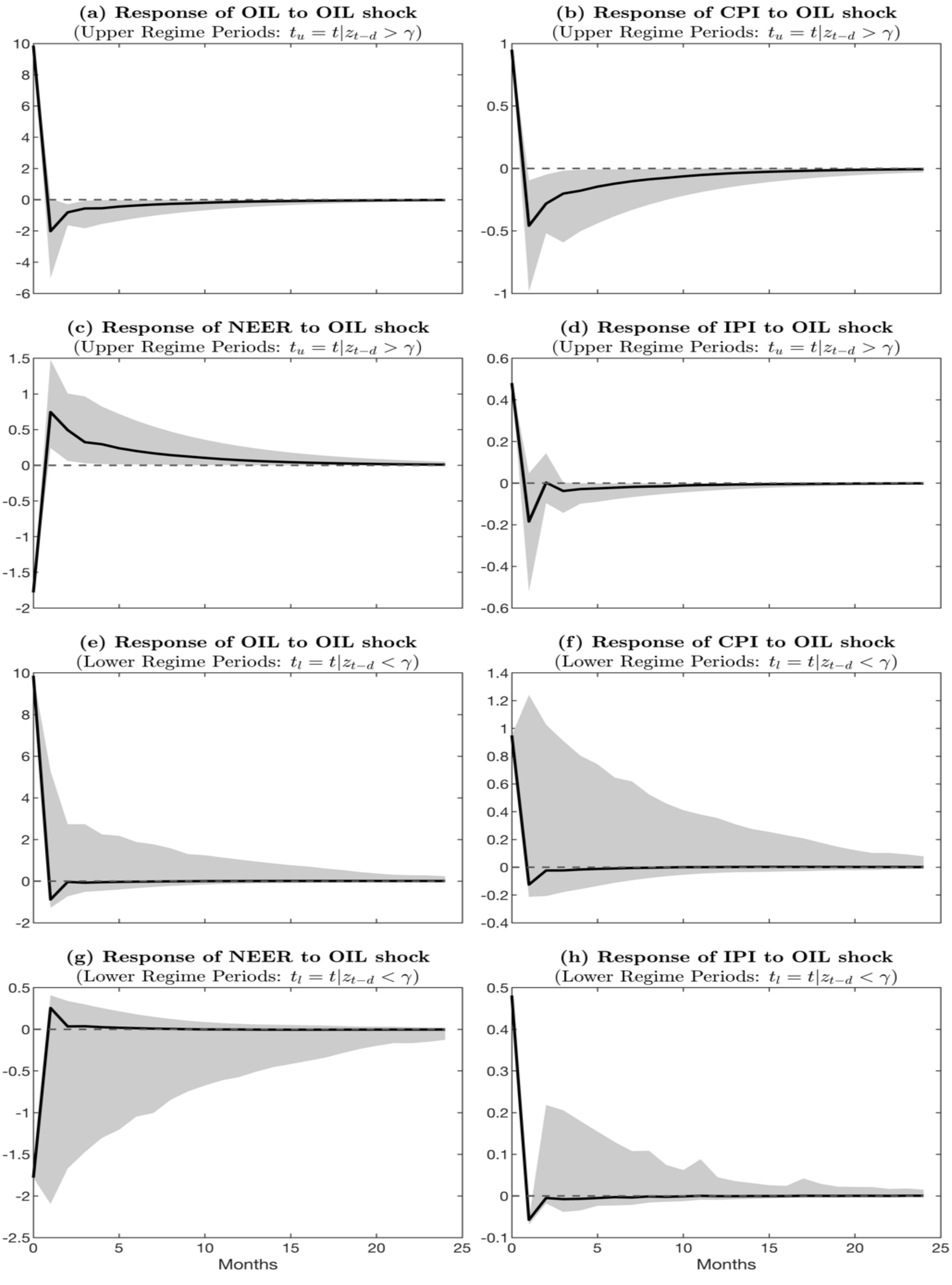
Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.

Figure 10: Responses to exchange rate shocks for South Africa



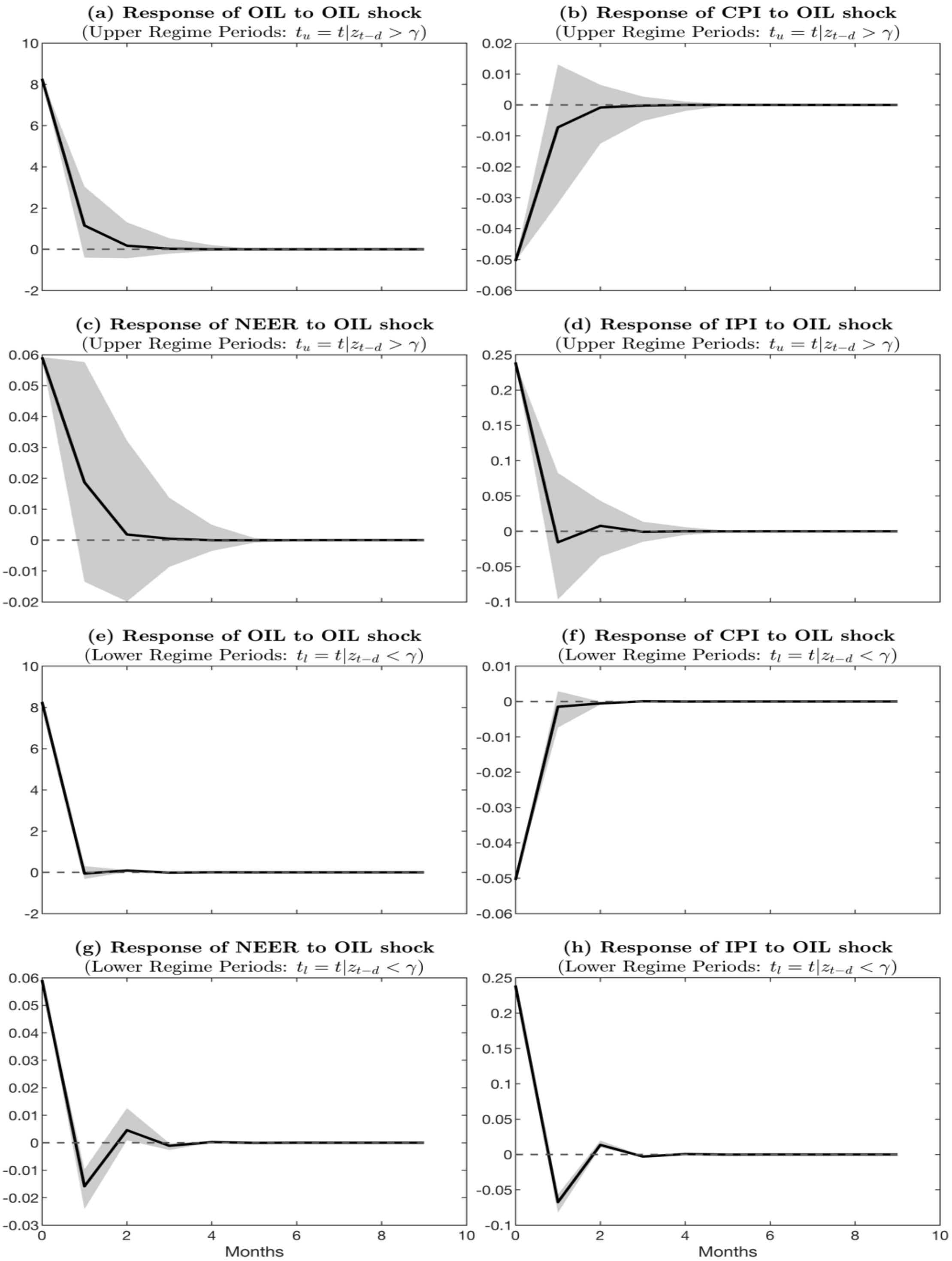
Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.

Figure 11: Responses to oil shocks for Brazil



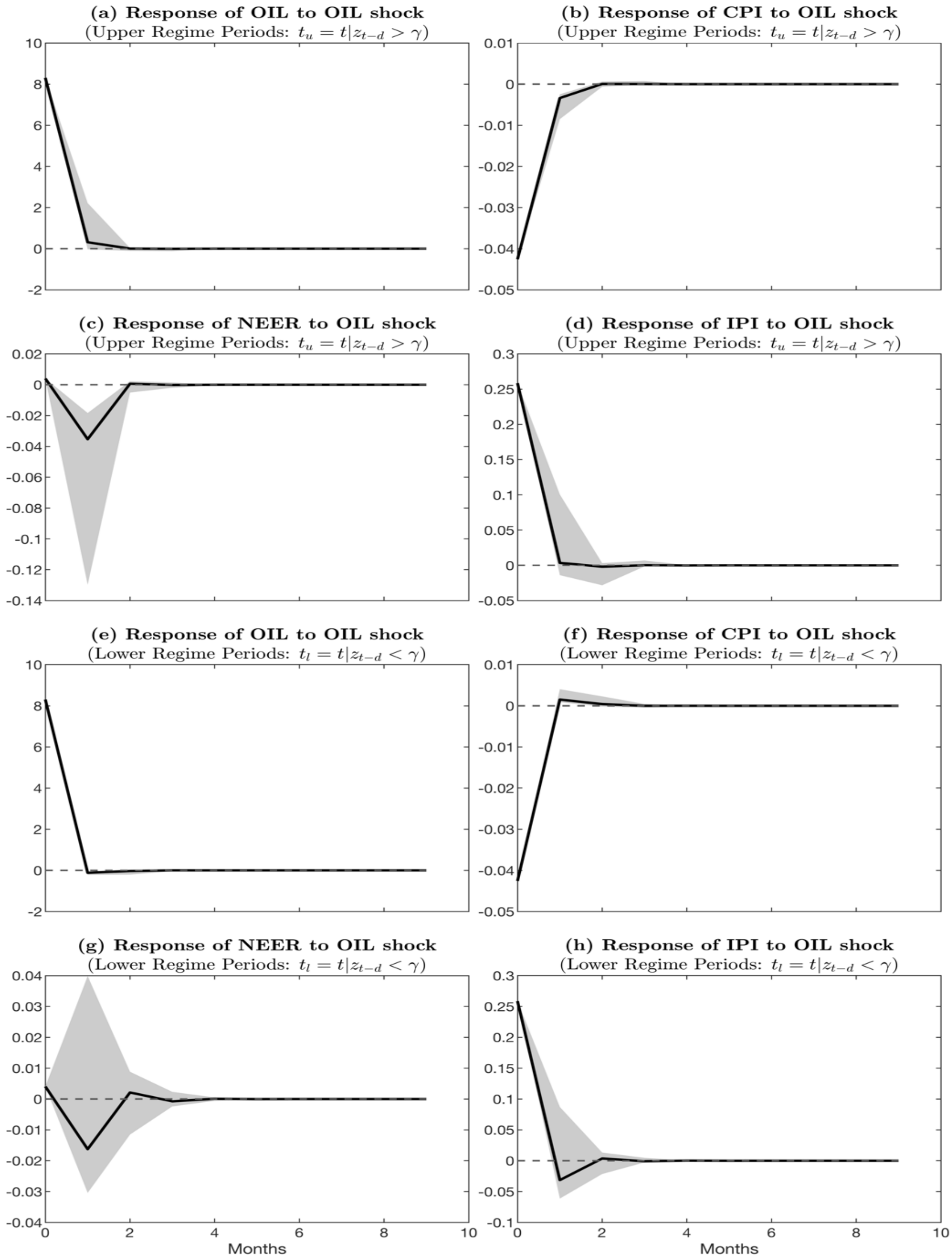
Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray are denotes the 95% confidence region.

Figure 12: Responses to oil shocks for Russia



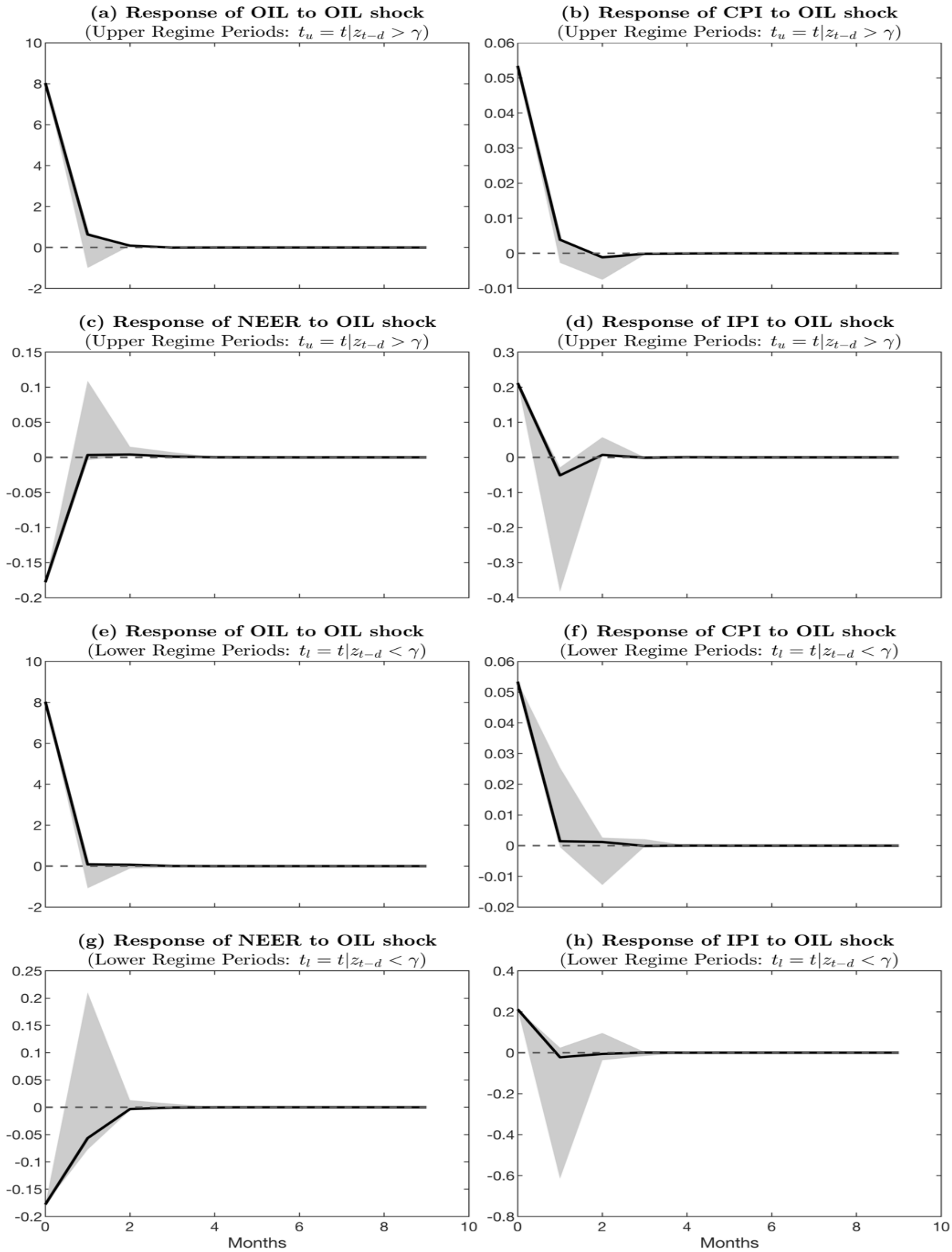
Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.

Figure 13: Responses to oil shocks for India



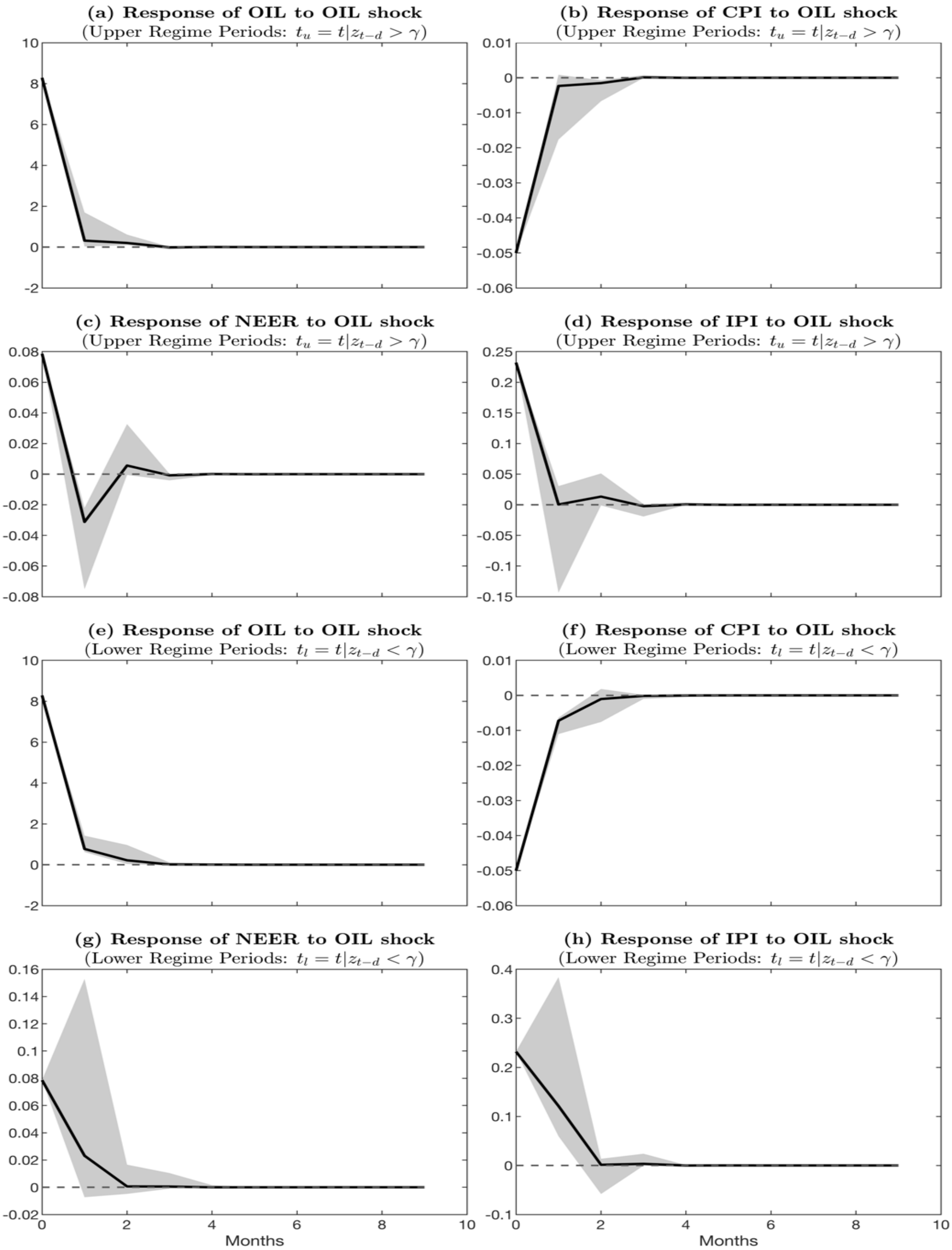
Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.

Figure 14: Responses to oil shocks for China



Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.

Figure 15: Responses to oil shocks for South Africa



Note: Generalized impulse responses are obtained with 1000 bootstrap repetitions. Gray denotes the 95% confidence region.