Does exchange rate management affect the causality between exchange rates and oil prices? Evidence from oil-exporting countries

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ARTICLE INFO

ABSTRACT

The bi-directional causality between exchange rates and oil prices of oil-exporting countries has been widely investigated since the oil crisis in the 1970s. The classical theoretical framework assumes that countries adopt free-floating exchange rate arrangements, and empirical studies seldom consider exchange rate restrictions when investigating oil exporters that always manage exchange rates. To address these limitations, this study designs a comparative analysis for three groups of oil-exporting economies that adopt different foreign exchange rate policies. The analysis aims to examine whether and how intervention behavior may distort the causal relationship between exchange rates and oil prices. We first show the non-linear causality relationships for countries with "free-floating exchange rate arrangements" in both long and short terms. Then, we establish how the managed floating policy can eliminate the impact of oil prices on exchange rates in bull markets but fail to prevent exchange rate depreciation in bear markets. In bear markets, a negative non-linear feedback from exchange rates to oil prices prevails in these countries. However, contrary to common wisdom, the strict "soft-pegged exchange rate arrangement" cannot remove all the linkages between exchange rates and oil prices. A small but significant response of exchange rates toward oil prices is detected for Kuwait and Saudi Arabia. A similar effect for Kazakhstan is only found in bear markets. In addition, this study re-investigates the relationship between exchange rate and the domestic currency price of oil. The conclusions are similar, except that the relationship is weakened in free-floating countries but strengthened in managed floating countries during the bear market periods.

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1. Introduction

Since the first oil crisis in the 1970s, the booms and busts in the oil market have always been accompanied with worldwide economic fluctuations. During the most recent oil crisis that started in June 2014, the global oil prices dropped from more than $127 per barrel to less than $30 per barrel. The largest exporting country (Saudi Arabia) attempted to fix its bilateral exchange rate by using administrative power. The second biggest oil exporter (Russia) sold a large number of foreign reserves to stabilize the Russian ruble, whereas the third largest exporting country (Canada) seldom intervened in the exchange market. Faced with the oil crisis, the top three exporting countries implemented different exchange rate policies. Mussa (1986) explains that the exchange rate policy on nominal rates, such as "free floating" and "fixed" rates,

can affect the behavior of actual exchange rates. Akram (2004) discusses the role of exchange rate policy on the relationship between oil prices and exchange rates and shows how monetary authorities in Norway distort this relationship by producing a non-linear causality between oil prices and exchange rates. Consequently, we expect the exchange rate policy to affect the relationship between exchange rates and oil prices. However, previous studies usually treat Russia or Saudi Arabia similar to Canada when discussing the relationship between oil prices and exchange rates. No study has ever investigated how and whether the three types of exchange rate policies distort the causality between oil prices and exchange rates. The current paper attempts to fill this gap.

Several classical studies suggest a causality, particularly the effect of oil prices on exchange rates, in the medium/long term based on two mechanisms: the terms of trade channel (Amano and van Norden, 1998; Buetzer et al., 2016) and the terms of wealth channel (Krugman, 1983; Buetzer et al., 2016). Other pertinent studies argue a reverse causal effect from exchange rates to oil prices based on the asset pricing theory (Akram, 2009; Chen et al., 2010). Zhang et al. (2016) focus on the

theoretical short-term transmission mechanism and suggest that "oil prices and exchange rates are set in active financial markets, and the movements in such market can be fast and short-lived." Beckmann et al. (2017) summarize these bi-directional short-term channels as "denomination channel" and "portfolio channel." Moreover, Akram (2004) suggests a new type of non-linear relationship between exchange rates and oil prices. Recently, Beckmann and Czudaj (2013a, 2013b) and Basher et al. (2016) have adopted the Markov regime switching structure (Hamilton, 1989) to further characterize the non-linear relationship between exchange rates and oil prices.

The aforementioned theoretical frameworks (i.e., terms of trade, terms of wealth, denomination, and portfolio channels) implicitly assume a free-floating exchange rate. Akram (2004) distinguishes different exchange rate policies to examine the causality between exchange rates and oil prices. The IMF Annual Report on Exchange Rate Arrangements and Exchange Restrictions state that major oil-exporting countries adopt different exchange rate mechanisms based on their different economic systems.[1] There are three types of exchange rate systems: free floating, managed floating, and soft pegged. A managed floating arrangement system intends to stabilize the exchange rate. Can it really reduce or eliminate the impacts of oil prices on exchange rates? Can the feedback effect from exchange rates to oil prices be weakened or even be offset? The soft-pegged exchange rate system strictly controls the exchange rate volatility within 2%. The strict-control scheme challenges countries to endure high inflation pressures and requires their central banks to hold considerable US dollar reserves when oil prices soar. Therefore, it is interesting to examine whether the country adopting the soft-pegged exchange rate arrangement has the capability to eliminate the bi-directional relationship in the long run. In other words, will there still be a link between exchange rates and oil prices resulting from limited control ability?

Countries that adopt managed floating arrangements also encounter similar risks of high inflation and lack of foreign reserves. Bearing the high inflation seems easier and more feasible than amassing foreign reserves, and hence, controlling appreciation tends to be more successful than preventing depreciation. Granville and Mallick (2010) and Ono (2013) confirm the success of the Bank of Russia in controlling the appreciation of the Russian ruble. This conjecture leads us to consider whether the asymmetric power may cause an asymmetric causality between oil prices and exchange rates in different regimes (Beckmann and Czudaj, 2013a; Basher et al., 2016).

To address the unsolved issues, this study designs a comparative empirical analysis. First, we analyze the cases of countries with free-floating arrangements and use the results as the benchmark. Then, we analyze how the results for oil-exporting countries with managed floating arrangement and soft-pegged arrangement differ from the benchmark results. Following the previous literature, we apply the Markov regime-switching vector auto-regression (VAR) model (or vector error correction model (VECM)) (Hamilton, 1989; Krolzig, 1997; Balcilar et al., 2015a, 2015b) to capture the non-linear bi-directional dynamic relationship between exchange rates and oil prices. The Bayesian estimation technique with the Gibbs sampling method are applied to efficiently estimate all the parameters.

This study offers the following contributions to the literature. First, this research adds to the literature by investigating the effect of exchange rate policy on the relationship between oil prices and the exchange rates of oil-exporting countries. By using the free-floating system as the benchmark, we capture the change in the causality between exchange rate and oil market under managed floating and soft-pegged arrangement systems. The results can fully illustrate how the causality between exchange rate and oil market evolves as the intervention on exchange rate strengthens. Second, this study extends the

work of Akram (2004) and further investigates the asymmetric power of exchange rate policies. For countries adopting exchange rate management, the central bank demonstrates asymmetric power in controlling currency appreciation and preventing currency depreciation. The Markov regime switching structure allows us to examine the asymmetric dependence between exchange rates and oil prices in different regimes. Third, this study considers an extensive list of nearly all of the most important oil-exporting countries, including the 17 largest oil-exporting countries, with each accounting at least 2% of the world's oil exportation.[2] The large dataset enables us to avoid selection bias and comprehensively analyze the causality between oil prices and exchange rates under different exchange rate systems.

The remainder of this paper is organized as follows. Section 2 introduces the literature review. Section 3 describes the data used in this study. Section 4 presents the methodology. Section 5 provides and discusses the empirical results. Section 6 presents the in-depth analysis. Section 7 presents the paper's conclusions.

2. Literature review

The previous literature shows a bi-directional causal relationship between oil prices and the exchange rates from both theoretical and empirical perspectives. First, the effect of oil prices on exchange rates in the medium/long term is derived from terms of trade channel and the wealth effect channel. For all economies where oil plays an important role, the oil shock affects the terms of trade, in which this oil shock effect is transmitted to non-traded goods and the real exchange. Through the wealth effect channel, a positive oil shock transfers relatively high wealth from oil importers to oil exporters, which causes currency appreciation in oil-exporting countries. Amano and van Norden (1998) construct the framework to capture the persistent effect of oil prices on real exchange rates in the long run through the terms of trade channel. Cashin et al. (2004) find that the trade models, such as purchasing power parity, show limited explanatory power in terms of the impacts of commodity prices on the exchange rates of 58 commodity-exporting countries. By contrast, Buetzer et al. (2016) show the oil prices significantly affect exchange rates through the terms of trade channel in both oil-exporting and industrialized countries.

Krugman (1983) offers a theoretical analysis of the wealth effect channel, suggesting that the increase in oil prices results in a reallocation of world wealth to a new portfolio equilibrium, and the new-asset market clearance requires exchange rates to adjust correspondingly. Bodenstein et al. (2011) apply a two-country DSGE model and show that oil price increase leads to exchange rate appreciation in oil-exporting countries. Kilian (2009) identify three types of oil shocks (i.e., supply shock, global demand shock, and oil specific demand shock) to accurately depict the wealth effect of oil shocks on exchange rates. Buetzer et al. (2016) have examined how the above three structural shocks affect the exchange rates of 44 countries and find that positive oil price shocks lead to a real appreciation (depreciation) in the exchange rates of oil-exporting (oil-importing) economies.

Second, some emerging theoretical and empirical researches intend to validate the reverse causality, particularly the effect of exchange rate on oil prices, in the medium/long term. The theoretical framework is based on the asset pricing model. Engel and West (2005) indicate that the rational expectation present-value model can help explain the relationship between exchange rate and macroeconomic fundamentals. Frankel (2006) demonstrates that global commodity markets, including oil markets, behave similarly in financial markets. Chen et al. (2010)

present a theoretical analysis based on the present-value model and conclude that exchange rates have a surprising explanatory power in predicting the financial markets for commodities. Akram (2009) provides empirical evidence on the weak US dollar and how it can lead to a rise in oil prices by using a structural VAR model. Thus, this study analyzes the long-term relationship between oil prices and exchange rates based on the term of trade, the term of wealth, and the asset pricing principle.

Several recent studies validate the short-term transmission between exchange rates and oil prices. Zhang et al. (2016) argue that both oil prices and exchange prices are the results of active financial markets, and each is possessed with strong predictive ability according to one's own fundamental factors; hence, the co-movement between oil price and exchange rates can be fast or short-lived. That is, oil prices and exchange rates will adjust fast, even immediately. Beckmann et al. (2017) argue that nominal exchange rate can affect nominal oil prices in the short term through the denomination channel, whereas the short-lived feedback effect of nominal exchange rates on oil prices can be produced through the portfolio channel. Moreover, Beckmann et al. (2017) suggest that daily frequency data can help verify the short-term transmission mechanism of the two channels, similar to those reported by Reboredo (2012), Balcilar et al. (2015a), Beckmann and Czudaj (2013b), and Zhang et al. (2016). This study follows the same reasoning when discussing the short-term bi-directional effects between oil prices and exchange rate by using nominal data.

In summary, the current literature can examine the bi-directional causality between exchange rates and oil prices in oil-exporting countries, but the findings are inconclusive. Reboredo (2012) finds a co-movement between oil prices and the exchange rate for Canada, Norway, and Mexico. Beckmann and Czudaj (2013a) suggest an ambiguous link between oil prices and exchange rates for Canada, Norway, Brazil, Norway, Russia, and UK. Zhang et al. (2016) find bi-directional effects with stronger impacts from energy prices to exchange rates for Canada, Australia, Norway, and Chile compared with those in the opposite direction. A number of other research focus on individual oil-exporting countries and investigate the relationship between oil prices and exchange rates, but the findings are also inconclusive. For example, Rautava (2004) finds that the correlation between the Russian exchange rate and oil prices is not statistically significant. Iwayemi and Fowowe (2011) conclude that positive oil shocks have no effect on Nigeria's exchange rate. By contrast, Kutan and Wyzan (2005) find a significant impact of oil prices on exchange rate and confirm the Dutch disease phenomenon in Kazakhstan. Granville and Mallick (2010) and Ono (2013) indicate that high oil prices can lead to the appreciation of the Russian ruble. Bouoiyour et al. (2015) apply the multivariate wavelet technique to confirm the significant bidirectional relationship between the Russian exchange rate and oil prices.

Most empirical studies on oil-exporting countries, particularly the developing countries, do not take into account how exchange rate restrictions may distort the presumed bi-directional causality between exchange rates and oil prices (Bouoiyour et al., 2015; Buetzer et al., 2016; Basher et al., 2016). For a rare exception, Akram (2004) argues that the interventions of Norway's monetary authorities on the Norwegian krone have led to a strong relationship between exchange rate and oil prices when the latter is particularly low or high. In addition, few studies analyze the short-term transmission mechanism of denomination channel or portfolio channel.

Some recent studies have discovered a non-linear relationship between exchange rates and oil prices. Hamilton (2003, 2011) offers some explanations on the non-linear effects of oil price shocks. Beckmann and Czudaj (2013a, 2013b) and Basher et al. (2016) apply Markov regime-switching models to investigate the causality between oil prices and exchange rates and subsequently find asymmetric relationships in different market regimes. This study evaluates the non-linear properties of the Markov switching (MS)-VAR and MS-VECM models.

3. Data

We use a daily dataset that includes oil prices and nominal exchange rates (EX). The data cover January 4, 2000 to December 31, 2015, but the specific date for each country depends on the effective period of the exchange rate policy. We mainly use Brent crude oil as the basis of discussing the relationship. The nominal Brent crude oil prices serve as a benchmark for the global crude oil market. The prices, which are expressed in US dollars per barrel, are collected from the website of the US Energy Information Administration. In accordance with the studies of Reboredo (2012), Balcilar et al. (2015a), Beckmann et al. (2016), and Zhang et al. (2016), the nominal exchange rate of an oil-exporting country in the present study is the bilateral rate expressed as the domestic currency per one unit of US dollar (i.e., an increase in nominal exchange rate implies a depreciation of the domestic currency).

The nominal exchange rate data in Fig. 1 are sourced from Bloomberg and grouped into three categories based on their different exchange rate arrangements, although we mainly considered the definition offered by Reinhart and Rogoff (2004). In particular, Reinhart and Rogoff (2004) argue that the annual report on exchange arrangements and exchange restrictions by the IMF is based on a country's declaration for defining the official de jure regime, but the true execution date sometimes differs from the announcement date. Therefore, Reinhart and Rogoff (2004) adjust the exchange rate regimes according to the countries' true execution dates, which leads to different starting or ending dates of the exchange rate arrangements from the IMF's definition for some countries. We therefore adopt the Reinhart–Rogoff classification for Kazakhstan, Russian, Norway, and Angola; for the other countries, the classification is the same between those of IMF and Reinhart and Rogoff (2004). Table 1 lists the countries under each type of exchange rate arrangement and the sample period for each country.

Table 1 also presents the descriptive statistics of the return of crude oil and all the exchange rates.[3] The exchange rate returns of countries with free-floating arrangements tend to have lower means, lower standard deviation, narrower fluctuation ranges and thinner tails than those in the other two categories in which countries with interventions. The descriptive statistics are more diverse among countries with soft-pegged exchange rate arrangements. Some countries, such as Iraq and Azerbaijan, have extremely unusual statistical properties. All these results suggest that the exchange rates of countries with free-floating arrangements are relatively stable and have comparably safe investments. All the return series show non-zero skewness and exhibit excess kurtosis.

4. Methodology

In this study, we apply three model categories to evaluate the relationships between exchange rates and oil prices. VAR models (Sims, 1980) are widely used to describe the dynamic relationship between economic and financial time series. The model is specified as follows:

$$\text{VAR model}: \Delta y_t = \mu + \sum_{i=1}^{p} \gamma_i' \Delta y_{t-i} + \varepsilon_t.$$

In this study, vector y_t includes two variables: the oil price and exchange rate. If the two series are nonstationary and co-integrated, then we adopt VECM, as suggested by Engle and Granger (1987), to capture this property.

$$\text{VECM model}: \Delta y_t = \mu + \sum_{i=1}^{p} \gamma_i' \Delta y_{t-i} + \alpha \beta' y_{t-1} + \varepsilon_t,$$

where $\beta' y_{t-1}$ is the stationary linear combination that represents the long-term relationship.

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[3] We convert the price series into return series by taking the log difference of price, $(\ln P_t - \ln P_{t-1}) * 100$. Due to page limitations, we do not report the log level of the series in this paper.
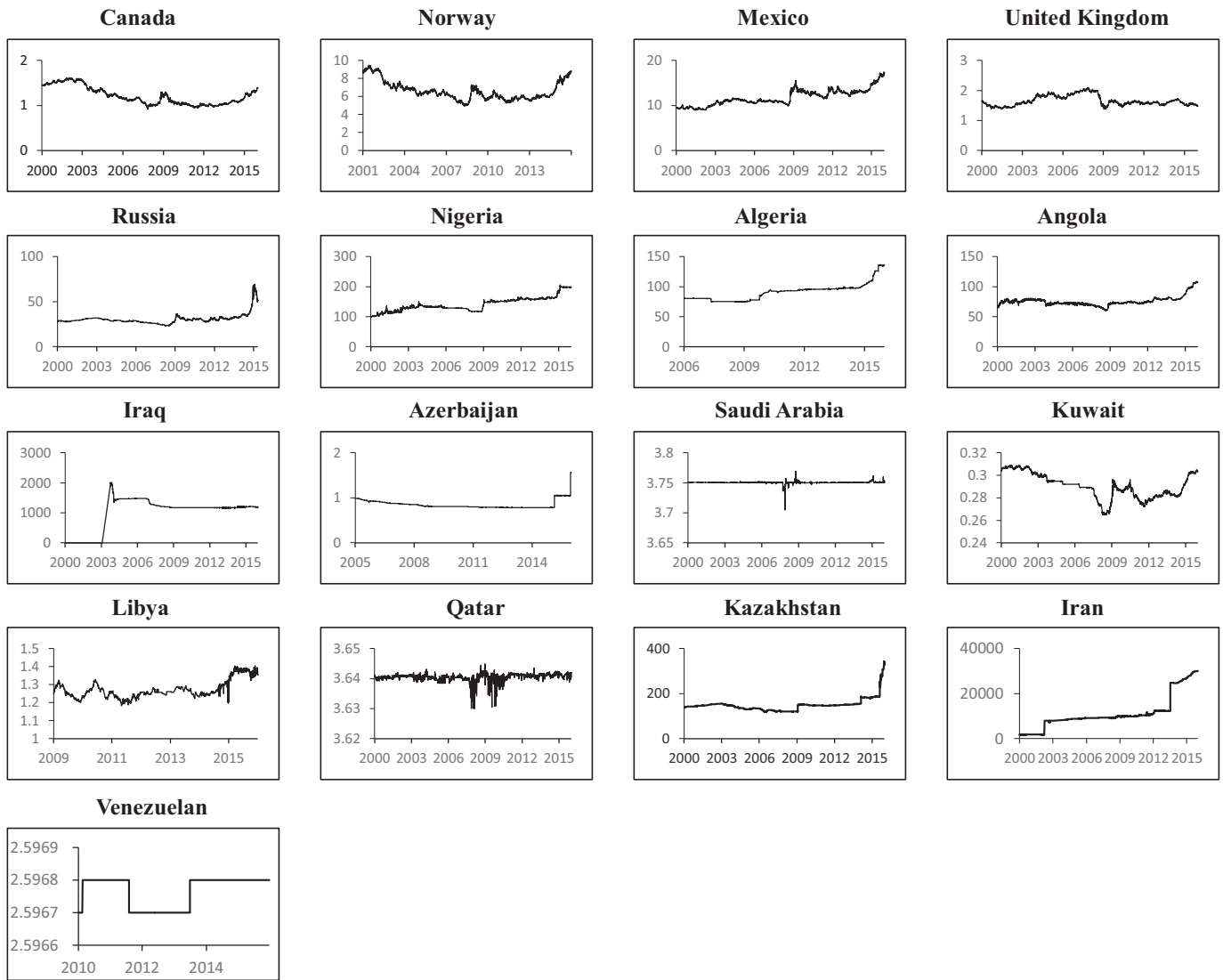
Fig. 1. The nominal bilateral exchange rate of oil-exporting countries.

To model the changes in a regime, Hamilton (1989) applies MS regression to capture the structure shifts or non-linearity in the parameters of the univariate autoregressive (AR) process (i.e., MS-AR). Krolzig (1997, 1998) extends the MS-AR model to the VAR model to simultaneously characterize the asymmetry in different regimes and the causality among multiple variates (MS-VAR and MS-VECM). The data generation process that underlies y_t is determined by the hidden regime variable s_t defined on a state space $(1,2)$. The MS-VAR and MS-VECM models can be presented as follows:

MS-VAR model:

$$\Delta y_t = \mu_{(s_t)} + \sum_{i=1}^{p} \gamma'_{i(s_t)} \Delta y_{t-i} + \varepsilon_{(s_t)t},$$

MS-VECM model:

$$\Delta y_t = \mu_{(s_t)} + \sum_{i=1}^{p} \gamma'_{i(s_t)} \Delta y_{t-i} + \alpha_{(s_t)} \beta' y_{t-1} + \varepsilon_{(s_t)t},$$

where $\beta' y_{t-1}$ is the state-independent co-integrating vector and $\alpha_{(s_t)}$ is the state-dependent adjustment vector. MS-VAR and MS-VECM have the following structural specification for the state:

$$\varepsilon_{(s_t)t} \sim \text{i.i.d.} N\left(0, \sum(s_t)\right),$$

where $\sum(s_t)$ is the variance–covariance matrix.

The initial vector $(y_{1-p}, \cdots, y_0)$ is fixed. The latent regime variable s_t follows an irreducible ergodic two-state Markov process and is governed by an unobservable Markov chain with the following transition probability matrix:

$$P = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}$$

and

$$P_{11} + P_{12} = 1; \text{ and } P_{21} + P_{22} = 1.$$

We let θ be the parameter vector that contains the regime transition probability P and all coefficients in the VAR model that include constant coefficient $\mu_{(s_t)}$, lag coefficient $\gamma'_{i(s_t)}$, and variance–covariance matrix $\sum(s_t)$.

The estimation procedure for MS-VECM (or MS-VAR) is as follows. The Bayesian inference is based on the posterior distribution of parameter θ, which combines the prior information and empirical likelihood function. Let $Y_T = (y_{1-p}, \cdots, y_{T-1})$. The likelihood function of Y_T, $p(Y_T|\theta)$ is

$$p(Y_T|\theta) = \prod_{t=1}^{T} \left[\sum_{s_t \in M} p(y_t|Y_{t-1}, \theta, s_t) p(s_t|Y_{t-1}, \theta) \right].$$

Table 1
Descriptive statistics and sample period.

	Mean	Maximum	Minimum	SD	Skewness	Kurtosis	Sample period	Observations
Exchange rate arrangements: free floating								
Canada	−0.0011	3.2540	−3.9981	0.5737	0.1392	6.0143	2000.1–2015.12	4061
Norway	0.0013	4.8683	−4.9710	0.7849	0.1709	5.5469	2001.1–2015.12	3808
Mexico	0.0142	7.0259	−6.6527	0.6708	0.6410	14.9868	2000.1–2015.12	4061
United Kingdom	−0.0022	2.9252	−3.4715	0.5595	−0.2624	5.3195	2000.1–2015.12	4061
Exchange rate arrangements: managed floating								
Russia	0.0191	9.7315	−9.7707	0.6085	1.2672	60.7019	2000.1–2015.6	3931
Nigeria	0.0169	12.7396	−12.7396	1.0219	0.3029	35.7924	2000.1–2015.12	4013
Algeria	0.0105	6.2872	−7.4154	1.0558	−0.0827	9.356	2000.1–2015.12	4045
Exchange rate arrangements: soft pegged								
Angola	0.0159	8.6896	−4.4558	0.3462	7.1349	201.5536	2005.1–2015.12	2776
Iraq	−0.2388	877.0951	−7.5378	14.9381	−58.6162	3441.246	2000.1–2015.12	3381
Azerbaijan	−0.0162	1.4511	−39.3864	0.9075	−38.3685	1537.331	2005.1–2015.12	2776
Saudi Arabia	0.0000	0.5892	−0.5629	0.0247	1.9833	211.0518	2000.1–2015.12	4058
Kuwait	−0.0001	2.5429	−3.1471	0.1702	−1.9084	87.3209	2000.1–2015.12	4060
Libya	−0.0061	10.1931	−10.1931	0.7736	−0.0346	86.8698	2009.1–2015.12	1762
Qatar	−0.0000	0.3053	−0.2833	0.0233	0.3524	55.7378	2000.1–2015.12	4050
Kazakhstan	0.0221	24.6391	−7.1472	0.6465	24.7706	838.3691	2000.1–2015.12	3965
Venezuela	2.56e-06	0.0039	−0.0039	0.0002	7.4213	501.1123	2010.1–2015.12	1505
Iran	0.0775	150.5910	−11.3578	2.7762	47.4092	2442.9350	2000.1–2015.12	3710
Oil price								
Brent	0.0160	18.1297	−19.8907	2.2876	−0.1521	8.1338	Corresponding	4264

Note: as the limitation of length, we only report the descriptive statistics for return series, and the log-level data shows similar pattern with return level data.
The sample period are decided by the classification of IMF and Reinhart and Rogoff (2004).

For the prior information, we assume that transition probability and state-specific parameters are independent, such that

$$p(\theta) = \underset{i=1}{\overset{M}{\subseteq}} p(\theta_i)p(P).$$

For the prior distribution, we follow the studies of Sims and Zha (1998) and Sims et al. (2008). The transition probability matrix takes a Dirichlet form. The error variance–covariance matrix takes an inverse Wishart density. The coefficients take multivariate normal distribution. Thus, on the basis of the Bayesian rule, the posterior distribution for θ is

$$p(\theta|Y_T) \propto p(\theta)p(Y_T|\theta).$$

The block expectation maximum (EM) algorithm is implemented to estimate the MS-VAR model and derive the posterior mode. This mode is then used as the initial value in the Gibbs sampling method to obtain the posterior estimator. We partition all of the parameters into four blocks for maximization, as suggested by Sims et al. (2008).

(1) Maximize the intercepts $\mu_{(s_t)}$.
(2) Maximize the autoregressive coefficients $\gamma_{i(s_t)}$.
(3) Maximize the error variance–covariance matrix $\sum(s_t)$.
(4) Maximize the transition matrix P.

For each block, EM is applied to optimize the log-likelihood function while holding all the other blocks constant.

The EM method iteratively applies two steps to obtain the maximum likelihood estimates. The first step is to compute the expected log-likelihood function based on a current parameter estimate, assuming that latent state variables are known. The second step is to estimate the parameter by maximizing the expected log-likelihood function in the first step and by using the result to estimate the latent variables. These two steps are iteratively applied until the optimal estimators are obtained.

After obtaining the posterior mode based on block EM, the Gibbs sampling method is implemented to derive the Bayesian estimator.[4]

The Gibbs method samples each variable in turn by holding others fixed from conditional distribution. This method is highly adaptable for cases with Bayesian framework. We use integer l to denote the iteration number. For example, $\theta^{(l)}$ represents the value in the lth iteration. In this instance, the Gibbs sampler undertakes the following steps:

(1) Based on the probability $\Pr(s_t = i|Y_T, \theta^{(l-1)})$ and the Baum–Hamilton–Lee–Kim filter and smoother, draw the state space for the Markov process $s_t^{(l)}$.
(2) From the conditional of the other parameter and the Dirichlet posterior, draw the transition matrix $P^{(l)}$.
(3) From the state-space $s_t^{(l)}$ and the MS-process data augmentation steps, estimate the regressions for each regime.
(4) From $P^{(l)}$, $s_t^{(l)}$, and other parameters from $(l-1)$, draw the error covariance $\Sigma^{(l)}$ from the inverse Wishart density function.
(5) Draw the state-dependent parameters from the multivariate normal distribution conditional on $P^{(l)}$, $s_t^{(l)}$, and $\Sigma^{(l)}$.
(6) Randomly permute the state and state coefficients by using a multinomial draw.

A two-stage procedure is applied to estimate MS-VECM. First, we apply the Johansen method to determine the co-integration relationship and obtain the error correction term $\beta'y_{t-1}$. Then, we plug this error term into the MS-VECM to estimate the remaining parameters. This scheme is implemented with the Bayesian MCMC estimation based on the Gibbs sampling. The details of the estimation have been described by Balcilar et al. (2015a, 2015b).

The impulse response function combines the effects of all of the coefficients, and thus, such function can derive a more thorough and realistic depiction of the results compared with the simple coefficient regression. Following the work of Balcilar et al. (2015a, 2015b), we focus on the regime-dependent impulse response functions in the analyses. Ehrmann et al. (2003) and Balcilar et al. (2015b) define the regime-dependent impulse response function as $\psi_{ks_t,h} = \frac{\partial E_t Y_{t+h}}{\partial u_{k,t}}$, where $u_{k,t}$ is the structure shock to variable k. However, the identification problem requires further consideration because the reduced-form shocks ε_t are the combinations of exchange rates and oil price shocks. This study applies the methodology suggested by Ehrmann et al.

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[4] The Gibbs sampling iterations are 2000 and 2500 for MS-VAR and MS-VECM, respectively, whereas the burn-in periods are 1000 and 500, respectively.

Table 2
Unit root tests.

Countries	ADF	PP
Exchange rate arrangements: free floating		
Canada	−1.2691	−1.2458
Norway	−1.6695	−1.4912
Mexico	−0.6236	−0.3988
United Kingdom	−1.5897	−1.6440
Exchange rate arrangements: managed floating		
Russia	−1.7487	0.6675
Nigeria	−0.8627	−1.0371
Algeria	0.1979	−0.4058
Exchange rate arrangements: soft pegged		
Angola	2.2037	2.4395
Iraq	−2.1140	−2.1138
Azerbaijan	1.3594	1.3099
Saudi Arabia	−6.6344***	−12.9360***
Kuwait	−1.7747	−1.1391
Libya	−1.2021	−1.9497
Qatar	−5.3106***	−50.8302***
Kazakhstan	3.2570*	4.4898**
Venezuela	−2.1536	−2.1566
Iran	−1.4805	−1.4761

Note: All of the return level series are the stationary, and we only report the results of unit root test for log-level data.
  * Represents significance at the 10% level.
 ** Represents significance at the 5% level.
*** Represents significance at the 1% level.

(2003) and Balcilar et al. (2015b) to solve the identification problem; that is, we use the recursive identification scheme (Sims, 1980).[5]

The estimated coefficients can validate the findings from the VAR or MS-VAR models. Thus, we explain the meanings of these estimates in the discussion section. We also apply the estimated coefficients of MS-VECM to explain the short-term relationship between oil prices and exchange rates when these two series are co-integrated. Latent regime variable s_t is assumed to follow a two-state Markov process. This approach is often suggested in the literature (e.g., Dumas, 1992; Engel, 1994; Beckmann and Czudaj, 2013a, 2013b; Basher et al., 2016). We define $s_t = 1, 2$ to represent State 1 and State 2 and conventionally depict a state with low volatility and high mean (i.e., bull markets) and a state with high volatility and low mean state (i.e., the bear markets), respectively (Basher et al., 2016).

5. Empirical results

5.1. Model selection and the market regimes

We first perform unit root tests and co-integration tests. Both ADF and PP tests show that all the log level series are non-stationary except for those of Saudi Arabia and Qatar, whereas the first difference of the log level data (return series) are all stationary (Table 2).[6] Consequently, we implement the co-integration test to detect the long-term relationship between oil prices and exchange rates. Table 3 presents the test results.[7] On the basis of the 5% significance level criteria, most oil-exporting countries do not exhibit a long-term relationship between

Table 3
Co-integration tests.

Countries	H_0	λ_{Trace}	H_0	λ_{Max}
Exchange rate arrangements: free floating				
Canada	r = 0	27.7978***	r = 0	26.2111***
	r ≤ 1	1.5867	r = 1	1.5867
Norway	r = 0	20.8783***	r = 0	17.376**
	r ≤ 1	3.5016*	r = 1	3.5016*
Mexico	r = 0	3.4535	r = 0	3.0006
	r ≤ 1	0.4529	r = 1	0.4529
United Kingdom	r = 0	8.1240	r = 0	5.5864
	r ≤ 1	2.5376	r = 1	2.5376
Exchange rate arrangements: managed floating				
Russia	r = 0	3.2912	r = 0	3.1666
	r ≤ 1	0.1247	r = 1	0.1247
Nigeria	r = 0	4.7447	r = 0	4.0792
	r ≤ 1	0.6655	r = 1	0.6655
Algeria	r = 0	6.2057	r = 0	5.7669
	r ≤ 1	0.4388	r = 1	0.4388
Exchange rate arrangements: managed floating				
Angola	r = 0	16.8259**	r = 0	12.6083*
	r ≤ 1	4.2176**	r = 1	4.2176**
Iraq	r = 0	10.1660	r = 0	5.8997
	r ≤ 1	4.2662**	r = 1	4.2662**
Azerbaijan	r = 0	9.8789	r = 0	9.3580
	r ≤ 1	0.5209	r = 1	0.5209
Kuwait	r = 0	12.2817	r = 0	10.6680
	r ≤ 1	1.6137	r = 1	1.6137
Libya	r = 0	18.5451**	r = 0	18.36043**
	r ≤ 1	0.1847	r = 1	0.1847
Kazakhstan	r = 0	27.7978***	r = 0	26.2111***
	r ≤ 1	1.5867	r = 1	1.5867
Iran	r = 0	5.4578	r = 0	4.4475
	r ≤ 1	1.3908	r = 1	1.3908
Venezuela	r = 0	6.4791	r = 0	5.9061
	r ≤ 1	0.3735	r = 1	0.3735

Note: The estimates results of the cointegration vector with statistics of maximal eigenvalue (λ_{Max}) and trace test (λ_{Trace}) are shown in above table.
  * Represents significance at the 10% level.
 ** Represents significance at the 5% level.
*** Represents significance at the 1% level.

their exchange rates and oil prices except for Canada, Norway, Angola, Libya, and Kazakhstan, and thus we adopt VECM for these countries.

Then, we consider the choice between non-linear MS structure (MS-VAR and MS-VECM) and linear model (VAR and VECM). Our selection criteria rely on both AIC (Akaike, 1974) and BIC (Schwarz, 1978). As shown in Table 4a, the MS-VECM model is preferred over the VECM model for five oil-exporting countries (Canada, Norway, Angola, Libya, and Kazakhstan). The results of the remaining countries in Table 4b suggest that the MS-VAR model is preferred over the VAR model except for Saudi Aribia, Kuwait, and Qatar. In addition, the estimation of the MS-VAR model for Venezuela fails to converge. Hence, we adopt the VAR model for Venezuela by default.[8]

Fig. 2 presents the estimated smoothed probabilities of different regimes for the "bull market." Four main types of smoothed probabilities are observed. For some oil-exporting countries, the smoothed probability frequently switches between 0 and 1. Moreover, the smoothed probabilities for some of the other countries switch from small positive numbers to larger positive numbers (but <1). For both groups of countries, the smoothed probability is always remarkably different from 0.5, which is consistent with the findings of previous studies (Beckmann and Czudaj, 2013a, 2013b; Basher et al., 2016). As a consequence, we

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[5] The recursive identification scheme is based on the Cholesky decomposition of covariance matrix $\Omega_{s_t} = L_{s_t} L'_{s_t}$ and the identified structural shocks. Balcilar et al. (2015b) offer detailed solutions for problem identification.

[6] The unit root results for oil prices and exchange rates are consistent with the results of previous studies, such as those by Balcilar et al. (2015b). The results are not reported in this paper but are available upon request.

[7] The co-integration test results in Table 3 assume a constant term in the VAR model, and the lag order is selected to be either AIC or BIC, or both. We also examine the co-integration relationship with other deterministic trend models, and the results are the same as those listed in Table 3.

[8] For the estimation, we apply AIC and BIC to choose the lag order. The results suggest that the model with the lag order is the best model in estimating the relationship between oil prices and exchange rates. The estimation of MS-VAR is not derived because the calculation does not converge in MS-VAR modeling.

Table 4a
The selection of VECM and MS-VECM.

		Canada	Norway	Angola	Kazakhstan	Libya
VECM	Log likelihood	−12,408.4	−12,764.8	−7016.7	−12,812.2	−5240.5
	AIC	24,910.8	25,623.5	14,127.3	25,718.3	10,575
	BIC	25,207.3	25,917	14,406	26,013.7	10,832.3
MS-VECM	Log likelihood	−11,857.6	−12,312.8	−1552	−7053.3	−4353
	AIC	23,911.2	24,821.5	3300	14,302.7	8902.1
	BIC	24,529.4	25,433.5	3881	14,918.6	9438.5

Note: Both the VECM model and MS-VECM model are with only one lag.

Table 4b
The selection of VAR and MS-VAR.

		Mexico	UK	Russia	Nigeria	Algeria	Saudi Arabia	Iraq	Azerbaijan	Kuwait	Qatar	Venezuela	Iran
VAR	Log likelihood	−13,158.9	−12,415	−12,713.9	−14,520.7	−14,695.6	179.8	−21,508.3	−9712.3	−7422.7	873.6	7960.6	−17,323.7
	AIC	26,377.8	24,890	25,487.8	29,101.4	29,451.2	−299.6	43,076.6	19,484.5	14,905.3	−1687.2	−15,861.2	34,707.3
	BIC	26,567.1	25,079.3	25,676.1	29,290.3	29,640.4	−110.4	43,260.4	19,662.4	15,094.6	−1498.0	−15,701.8	34,893.9
MS-VAR	Log likelihood	−12,397.8	−11,969	−10,490.7	−11,732.2	−13,092.4	−2,534,436	−13,668.7	−5524.9	−9618.1	−6,079,498		−13,795.6
	AIC	24,923.6	24,066	21,109.4	23,592.4	26,312.8	5,069,000	27,465.4	11,177.8	19,364.2	12,159,124		27,719.2
	BIC	25,327.4	24,469.8	21,511.1	23,995.4	26,716.3	5,069,403.7	27,857.5	11,557.3	19,768	12,159,527.6		28,117.2

Note: Both the VAR model and MS-VAR model are with only one lag. When we estimate the MS-VAR model for Venezuela, the program fails to converge and does not report the results.
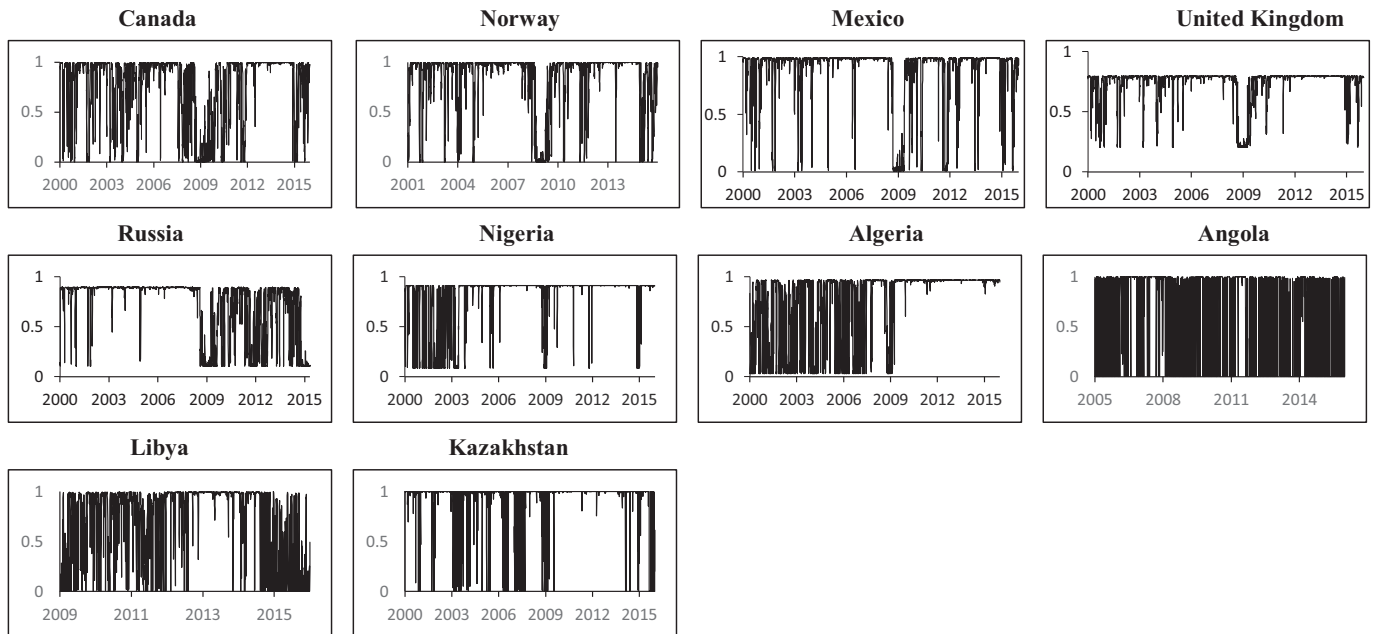

Fig. 2. Smoothed probabilities in bull market. Notes: The smoothed probabilities in bull market for Canada, Norway, Angola, Libya and Kazakhstan are calculated by the MS-VECM model, and the results for the other countries are estimated by the MS-VAR model.

can easily classify the bull markets and the bear markets.[9] However, for some countries, the smoothed probability always clusters around 0.5 (Appendix A). The results do not allow us to classify different regimes; moreover, the presence of a single regime rather than two regimes is likely. This scenario mostly occurs among exporting countries that adopt soft-pegged exchange arrangements to stringently restrict the

movement of their exchange rates. We then adopt the VAR model instead of the MS-VAR model for these countries.[10] In the case of Iraq, Azebaijan, and Iran (Appendix A), the comparably smooth probabilities are almost always equal to 1. Clearly, the VAR model is sufficient.

The two regimes classified as bull market and bear market correspond well with the low-volatility regime and the high-volatility regime

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[9] The "frequent switch" characteristic in this paper is consistent with that in the study of Beckmann and Czudaj (2013b). The reason lies in data frequency. We use daily data in our study. Oftentimes, exchange rates or oil prices rise or decline drastically on certain days (see Figures 1 and 3). These days are referred to as "Black Fridays." Hamilton and Susmel (1994) have shown that the Markov regime structure can effectively capture these sudden shocks. Consequently, the smoothed probability depicts a high frequency of switching.

[10] Hamilton and Susmel (1994) suggests that the Markov switching structure is applicable only when the market regime persists for a sufficient period. Nonetheless, we also estimate the MA-VAR models and compare the results of MS-VAR model with that of the simple bivariate VAR model. Given the similarity of the results, we find that using the VAR model is sufficient in analyzing the relationship between oil prices and exchange rates of many countries with "soft-pegged" arrangements.
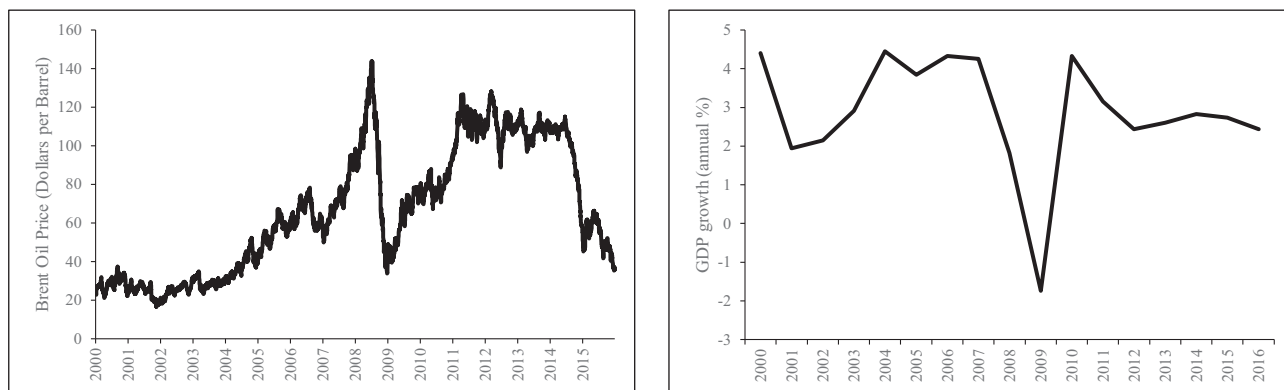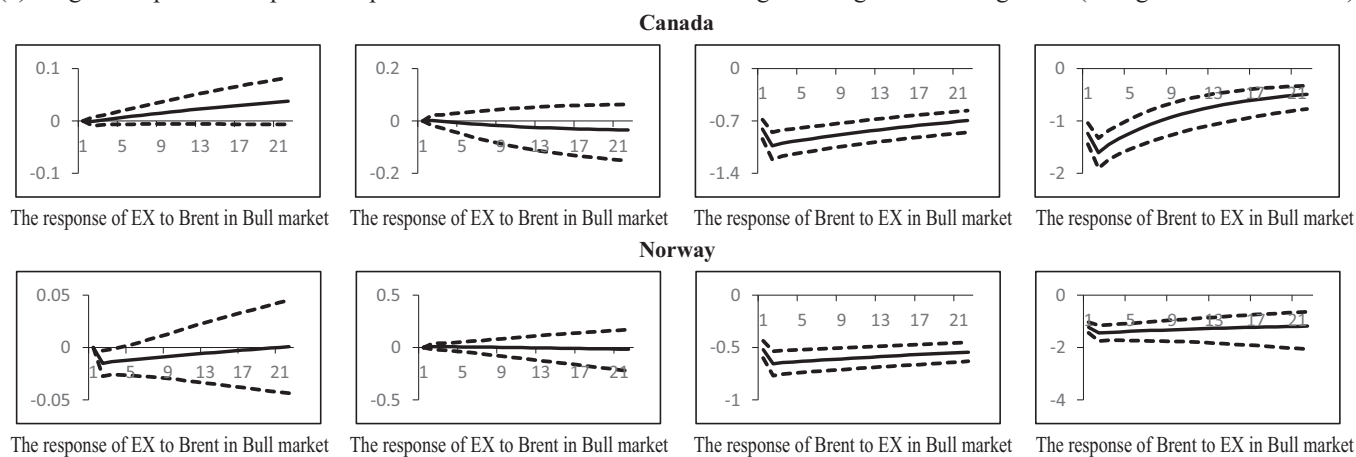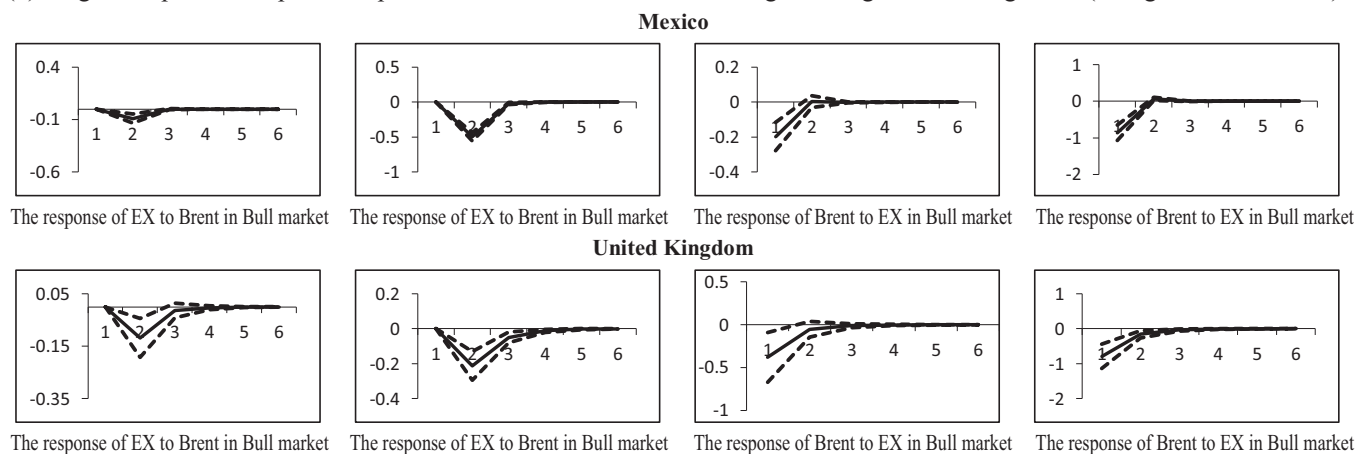
Fig. 3. Brent oil price and world GDP growth.

(a). Regime-dependent Impulse Response for Countries with Free Floating Exchange Rate Arrangement (Using MS-VECM model)

Canada

The response of EX to Brent in Bull market   The response of EX to Brent in Bull market   The response of Brent to EX in Bull market   The response of Brent to EX in Bull market

Norway

The response of EX to Brent in Bull market   The response of EX to Brent in Bull market   The response of Brent to EX in Bull market   The response of Brent to EX in Bull market

(b). Regime-dependent Impulse Response for Countries with Free Floating Exchange Rate Arrangement (Using MS-VAR model)

Mexico

The response of EX to Brent in Bull market   The response of EX to Brent in Bull market   The response of Brent to EX in Bull market   The response of Brent to EX in Bull market

United Kingdom

The response of EX to Brent in Bull market   The response of EX to Brent in Bull market   The response of Brent to EX in Bull market   The response of Brent to EX in Bull market

Fig. 4. (a). Regime-dependent impulse response for countries with free floating exchange rate arrangement (using MS-VECM model). (b). Regime-dependent impulse response for countries with free floating exchange rate arrangement (using MS-VAR model). Note: EX represents the shocks of exchange rate price, and Brent represents the shocks of Brent oil price.

reported by Balcilar et al. (2015a) and Basher et al. (2016), respectively.[11] The low-volatility regime matches the time of economic boom and oil price soaring, whereas the high-volatility regime is in line

with economic recession and oil crisis. Although the bull and bear market periods are not synchronized for all countries, the worldwide bull and bear markets defined by global GDP growth rates and oil prices are well captured (Figs. 2 and 3). For example, the smoothed probabilities of exporting countries with "free-floating arrangement" and "managed floating arrangement" (Fig. 2) show that most of the low-volatility (bull market) regime has occurred between January

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[11] The bull and bear regimes for each country are not always synchronized. Basher et al. (2016) explain that exchange rates are affected by many macroeconomic factors, including policies, trade and financial openness, and exchange rate regimes, among others.

2000 and July 2008.[12] During this period, the world oil price increased by more than five times from 24.4 USD/barrel to 127.1 USD/barrel, while the world GDP growth rate suggests that this period has experienced economic expansion (Fig. 3). On the contrary, small probabilities of high volatility (bear market) appear from August 2008 to October 2010 and from January 2014 to June 2015 (Fig. 2). The two periods coincide with the two oil crises of 2008 and 2014, which have been driven by the financial crisis and caused by a US shale oil supply shock, respectively. In both of these two bear regimes, the oil price dropped by >50% (Fig. 3). The exchange rates of many oil-exporting countries depreciated by 50%–100% (Fig. 1). The world GDP growth rate in Fig. 3 further confirms the economic stagnation or recession during these periods.

5.2. Free-floating exchange rate arrangement

We investigate four well-documented oil-exporting countries, namely, Canada, Norway, Mexico, and UK, which execute free-floating exchange rates (Reboredo, 2012; Beckmann and Czudaj, 2013a; Basher et al., 2016; Zhang et al., 2016). Recall that we choose the MS-VECM model for Canada and Norway and the MS-VAR model for Mexico and UK. The results of the impulse response functions from the MS-VECM model in Fig. 4(a) show a long-term unidirectional but non-linear causality, particularly for the effect of exchange rates on oil prices, for Canada and Norway. The exchange rates in Canada and Norway negatively affect oil prices, while the effect of oil price on exchange rate is insignificant. The long-term effects persist for >22 trading days and converges to zero very slowly. These results imply that the appreciation of exchange rate in these countries can cause the world oil price to rise in the long term. As further shown by Fig. 4(a), the negative effect of exchange rate on oil price is stronger in bear markets than those in bull markets. This finding is consistent with the stylistic fact that investors are more sensitive in bear markets than those in bull markets.

The estimated coefficients of MS-VECM model in Table 5a further suggest that the exchange rates in Canada and Norway affect oil prices in the short term as well. These short-term effects have non-linear characteristics, e.g., larger causality in bear markets than that in bull markets. In Canada, the impact of exchange rate on oil price is approximately −0.2419 in bull markets and −0.4962 in bear markets. In Norway, the coefficient is nearly −0.1534 in bull markets and −0.2411 in bear markets.[13] The short-term effect of oil price on exchange rate is detected only in Norway during the bull market (−0.0160). Overall, the findings from impulse response function analysis and the estimated coefficients imply that the exchange rate shocks of Canada and Norway have dramatic non-linear effects on oil prices in both long and short terms.[14]

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[12] As the smoothed probabilities of "soft-pegged" oil-exporting countries do not show strong non-linearity, we define the two regimes according to the smoothed probabilities for countries with "free-floating" and "managed floating" arrangements.

[13] Although the coefficient of Norway's exchange rate to the oil price in the bear market is insignificant, its corresponding P-value is nearly 0.12. Hence we argue that the response of oil prices toward exchange rates in bear markets is larger than that in bull markets.

[14] We conduct further review on the literature carefully and find a few relevant articles. The results suggest that, different model specifications and different sample periods affect the short-run and long-run relationships between a country's exchange rate and the crude oil price. For example, Akram (2004) find there is a short run effect from the oil price to the Norwegian exchange rate but no long run effect. Specifically, Akram (2004) suggests that, in the long run, the exchange rate is completely determined by the purchasing power parity (PPP). On the other hand, PPP is rarely considered in the further literature including the current paper. Within the threshold auto-regression framework, Mohammadi and Jahan-Parvar (2012) find there is no short run causality between real exchange rate and real oil price but oil price has a long run impact on the exchange rate of Norway. Similarly, Tryggestad and Haagensen (2017) consider both the ordinary least squares method and the Markov switching model, and support statistically significant short-term and long-term relationships between the Norwegian exchange rate and oil price. Thus, there are no unanimous conclusions regarding the short run and long run effects between oil price and exchange rates in Norway and Canada, which suggests further studies.

Table 5a
Estimation results for countries with free floating arrangement (using MS-VECM model).

		Bull market					Bear market					P11	P22	Likelihood
		Intercept	Exchange rate	Oil	ECT	Σ	Intercept	Exchange rate	Oil	ECT	Σ			
Canada	Exchange rate	−0.3919* (0.2292)	−0.0620*** (0.01926)	−0.0034 (0.0050)	0.0008 (0.0005)	0.1921	0.6173 (0.9829)	−0.0386 (0.0345)	0.0056 (0.01089)	−0.0012 (0.0021)	0.8834	0.9715	0.8949	−11,857.5970
	Oil	3.9183*** (0.9919)	−0.2419*** (0.0813)	−0.0127 (0.0194)	−0.0082*** (0.0021)	3.0479	13.4900*** (3.5096)	−0.4962*** (0.1455)	−0.0153 (0.0333)	−0.0300*** (0.0076)	11.9776			
Norway	Exchange rate	−0.2675 (0.4426)	−0.0242 (0.0188)	−0.0160** (0.0074)	0.0002 (0.0004)	0.4507	0.5227 (2.3867)	−0.0282 (0.0394)	0.0116 (0.0189)	−0.0003 (0.0022)	1.7026	0.9837	0.8907	−12,312.7617
	Oil	5.2648*** (1.2280)	−0.1534*** (0.0519)	−0.0212 (0.0189)	−0.0048*** (0.0011)	3.1001	5.0237 (6.7861)	−0.2411 (0.1564)	−0.0100 (0.0456)	−0.0049 (0.0063)	15.1750			

Note: Σ refers to the standard deviation of each state. Standard deviation statistics are shown in parentheses. The transition probabilities are reported as P11 and P22. ECT represents the error correction terms.
* Represents significance at the 10% level.
** Represents significance at the 5% level.
*** Represents significance at the 1% level.

Table 5b
Estimation results for countries with free floating arrangement (using MS-VAR model).

		Bull market				Bear market				P11	P22	Likelihood
		Intercept	Exchange rate	Oil	Σ	Intercept	Exchange rate	Oil	Σ			
Mexico	Exchange rate	−0.0007	−0.0152	−0.0002	0.2829	0.1262***	−0.0181	0.0123	3.8027	0.9813	0.8685	−12,397.83
		(0.0333)	(0.0633)	(0.0167)		(0.0417)	(0.0287)	(0.0103)				
	Oil	0.0567*	−0.1686***	0.0245***	2.0757	−0.3206***	−0.3442***	0.0576***	16.8434			
		(0.0406)	(0.0323)	(0.0080)		(0.0753)	(0.0312)	(0.0121)				
United Kingdom	Exchange rate	−0.0126	0.0298	−0.0079	0.4123	0.0569	0.1479*	−0.0056	17.3427	0.9605	0.8899	−11,969.02
		(0.0320)	(0.1054)	(0.0160)		(0.0490)	(0.1049)	(0.0142)				
	Oil	−0.0427	−0.1835***	0.0326**	0.4256	−0.3293*	−0.2282***	0.0590***	17.5761			
		(0.2036)	(0.0498)	(0.0194)		(0.2119)	(0.0598)	(0.0211)				

Note: Σ refers to the standard deviation of each state. Standard deviation statistics are shown in parentheses. The transition probabilities are reported as P11 and P22.
* Represents significance at the 10% level.
** Represents significance at the 5% level.
*** Represents significance at the 1% level.

The impulse response functions of the MS-VAR models depict a consistent bi-directional causality in the short term between the respective exchange rates and oil prices for Mexico and UK (Fig. 4(b)). First, we find a negative response of exchange rates toward oil prices in both regimes. That is, consistent with the portfolio channel argument, a positive shock on the oil market promotes the exchange rate. The response reaches the maxima on the second day in general and lasts for 2 to 3 days. Second, the oil market responds negatively toward the shock in both regimes, but the effect lasts for only 1 day. This finding confirms the inverse effect of exchange rate on oil prices based on the denomination channel hypothesis. When the local currency appreciates, the oil price labeled in US dollars will decrease, which induces a high demand and return of the oil market. Fig. 4(b) also presents a similar non-linear short-term relationship between exchange rate and the oil market, given that both responses are stronger in bear markets than in bull markets. The coefficient estimates in Table 5b validate the prevalence of the non-linear causality in the short term for Mexico and UK. The estimated coefficients of exchange rate in the oil price equation in the bear market are significantly negative and much stronger than those in the bull market for both countries. However, the estimated coefficient of oil price in the exchange rate equation is not statistically significant in both regimes for the two countries.

In summary, the estimation results show a negatively significant one-lag effect of exchange rates on the oil market; however, no significant one-lag effect of the oil market on the exchange rates for Mexico and UK is observed. The healthy economic systems and exchange rate policy self-selection may have contributed to these results. In particular, the economic foundations, including the exchange rates of developed countries, are sufficiently healthy to not be affected by a single industry shock despite the anticipated impact of the oil industry. Therefore, the free-floating exchange rate arrangement is chosen.

The above findings altogether confirm the classical theoretical analysis and provide new angles for empirical research. First, Beckmann and Czudaj (2013b) explain that weighted exchange rates and oil prices have a simultaneous long-term and short-term (time-varying) relationship. The present study shows that both long-term and short-term causalities depend on a country's specific characteristics even if all the major oil-exporting developed countries implement free-floating arrangements. Second, our results suggest that both denomination channel and portfolio channel provide the theoretical foundation for short-term co-movement. The portfolio channel causes a negative response of exchange rate toward oil price shock, whereas the denomination channel explains the response of the oil market toward the exchange rate shock. Third, Basher et al. (2016) focus on the impact of oil prices on exchange rates within the MS structure while ignoring the possibility of a bi-directional causality between exchange rates and oil prices. Our findings suggest that applying the MS-VAR structure may be appropriate in examining the relationship between oil prices and exchange rates. Fourth, Zhang et al. (2016) argue that the

relationship between oil prices and exchange rates can be captured using high-frequency data but not with low-frequency data. Our findings detect causal effects in the short term (1 to 3 days). Thus, data frequency may explain the ambiguous relationship found in the work of Beckmann and Czudaj (2013a) in which monthly data are employed.

5.3. Managed floating exchange rate arrangement

Fig. 5 presents the regime-dependent impulse responses of countries with managed floating exchange rate arrangements (Russia, Nigeria and Algeria). A similar pattern is detected, particularly with the non-significant response of exchange rate toward the oil shock in bull markets, whereas a significantly negative response is detected in bear markets that have attained the maximum in the second day and lasting for at least 3 days. In bear markets, the maximum impact of the oil prices on the Russian ruble is approximately −0.08, which is slightly larger than those on the Nigerian and Algerian currencies (approximately −0.05) in absolute values.

Upon comparing the impulse responses of exchange rates toward oil shocks under the managed floating exchange arrangement and free-floating arrangement systems, we find on the basis of exchange rate management that the impact of oil prices on exchange rates is successfully eliminated in bull markets, but a significant response remains in bear markets. Investor sentiment in bull markets may account for this result. An alternative explanation is the asymmetric powers of the central banks of Russia, Nigeria, and Algeria in managing the depreciation and appreciation of their respective exchange rates. When global oil price rises (drops), these countries will experience appreciation (depreciation) pressures. The central banks of Russia, Nigeria, and Algeria will then intervene in their respective exchange markets by purchasing (selling) foreign currency. However, they become more successful in controlling the appreciation of their own currencies (by issuing additional local money) than in preventing the depreciation of their exchange rates (by using limited foreign reserves in US dollars). This asymmetric power has been confirmed by empirical observations. For example, the Bank of Russia conducted EX sales operation by >120 times to reduce its foreign reserve reduction by 20%–30% in 2014 and 2015, but the Russian ruble continued to depreciate by >100% from 1 USD = 32 RBL to 1 USD = 64 RBL[15] since 2014 (Bank of Russia Database[16]). Ono (2013) and Granville and Mallick (2010) document the Bank of Russia's successful control of the Russian ruble appreciation by increasing money supply. Iwayemi and Fowowe (2011) argue that only negative oil shocks can significantly affect the

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[15] Russia has adopted an indirect pricing method to represent its foreign exchange rate. For example, 1 USD = 64 RBL or "RUB/USD" in Russia. The Russian ruble depreciates (appreciates) with the increase (decrease) of RUB/USD.
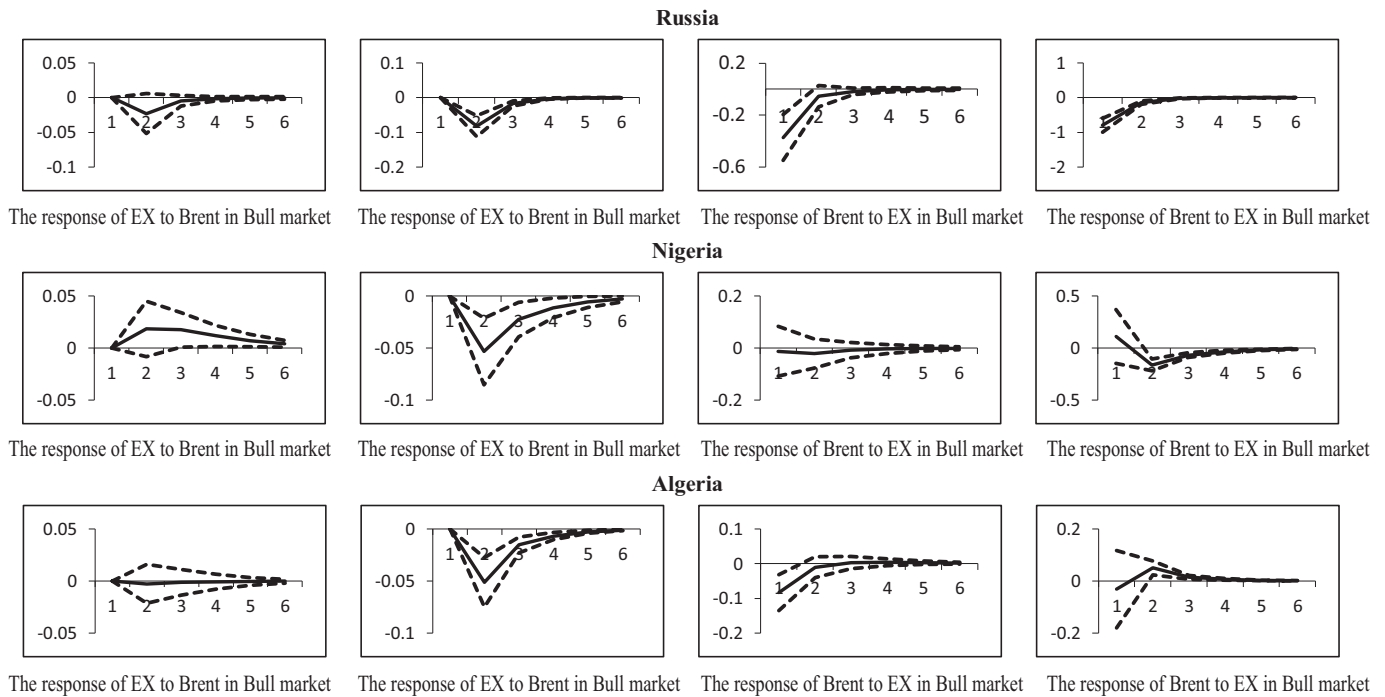[16] For more details regarding these data, refer to the Bank of Russia website at http://www.cbr.ru/eng/.

Russia

| The response of EX to Brent in Bull market | The response of EX to Brent in Bull market | The response of Brent to EX in Bull market | The response of Brent to EX in Bull market |

Nigeria

| The response of EX to Brent in Bull market | The response of EX to Brent in Bull market | The response of Brent to EX in Bull market | The response of Brent to EX in Bull market |

Algeria

| The response of EX to Brent in Bull market | The response of EX to Brent in Bull market | The response of Brent to EX in Bull market | The response of Brent to EX in Bull market |

Fig. 5. Regime-dependent impulse response for countries with managed floating exchange rate arrangement (using MS-VAR model). Note: EX represents the shocks of exchange rate price, and Brent represents the shocks of Brent oil price.

exchange rate in Nigeria. Our results are consistent with Iwayemi and Fowowe (2011); at the same time, we offer an explanation to this non-linear relationship in the view of managed floating exchange rate policy. Moreover, this study is the first one to investigate the impact of oil prices on the exchange rate of Algeria.

The responses of the oil market toward the exchange rate shock have negative and non-linear patterns with small variations across Russia, Nigeria, and Algeria (Fig. 5). In Russia, the exchange rate has a significant negative effect on oil price, and the impact is stronger in the bear market (−0.08) than that in the bull market (−0.02). In Nigeria, the exchange rate has no significant effect on oil price in the bull market, but a negative effect (−0.05) prevails in the bear market, and it starts at the end of the first day and disappears at the beginning of the fifth day. In Algeria, a negative response (−0.05) of oil prices toward exchange rate shock prevail in the bull market, and the response lasts for only 1 day. By contrast, in the bear market, the response is negative (−0.003) initially and then becomes positive and lasts for approximately 2 days.

Upon comparison, the response of oil markets toward exchange rates under free-floating arrangements is considerably mitigated when the exchange rate is managed. The two possible explanations are as follows. First, the three countries with managed floating exchange arrangements do not have strong influencing powers in the world economy. Thus, the exchange rates of Russia, Nigeria, and Algeria cannot affect world oil price as strongly as those seen among developed countries. Second, an exchange rate policy is self-selected. Given their high dependence on the oil industry, these countries have opted to manage their respective exchange rate policies. Moreover, interventions are employed for the exchange rates in these countries. Thus, instead of reflecting the true market information, oil market information is utilized; however, the responses of the above countries toward exchange rates are less effective compared with those of developed countries.

The estimation results in Table 6 further strengthen the non-responsiveness of oil markets toward exchange rates in the three countries. All the coefficients of oil price are statistically insignificant

Table 6
Estimation results for countries with managed floating arrangement (using MS-VAR model).

		Bull market				Bear market				P11	P22	Likelihood
		Intercept	Exchange rate	Oil	Σ	Intercept	Exchange rate	Oil	Σ			
Russia	Exchange rate	−0.0127	0.1430	−0.0005	0.2775	0.0936***	0.1225*	−0.0153	4.3323	0.9667	0.9088	−11,761.4
		(0.0580)	(0.1911)	(0.0294)		(0.0369)	(0.0772)	(0.0151)				
	Oil	0.0633	−0.0525	0.0232	1.7651	−0.1921	0.0642***	0.0780***	9.6411			
		(0.0930)	(0.0582)	(0.0229)		(0.1067)	(0.0233)	(0.0246)				
Nigeria	Exchange rate	0.0070	0.4936***	−0.00006	1.4329	−0.0542**	−0.0133	0.0278***	4.3933	0.9690	0.8536	−13,560.78
		(0.0204)	(0.1763)	(0.0130)		(0.0227)	(0.1742)	(0.0107)				
	Oil	0.0048	0.0294	0.3172***	4.1461	−0.0171	−0.0142	0.4901***	28.0387			
		(0.0189)	(0.0216)	(0.0585)		(0.0507)	(0.0165)	(0.0601)				
Algeria	Exchange Rate	−0.0094	0.4071***	0.0099	0.8840	0.0470**	−0.0895	0.0115**	6.0295	0.9643	0.8783	−14,696.1
		(0.0202)	(0.0983)	(0.0087)		(0.0192)	(0.0938)	(0.0046)				
	Oil	0.0091	−0.0018	0.3442***	1.3336	0.0025	−0.0223**	0.4035***	17.9002			
		(0.0125)	(0.0188)	(0.0149)		(0.0327)	(0.0108)	(0.0189)				

Note: Σ refers to the standard deviation of each state. Standard deviation statistics are shown in parentheses. The transition probabilities are reported as P11 and P22.
* Represents significance at the 10% level.
** Represents significance at the 5% level.
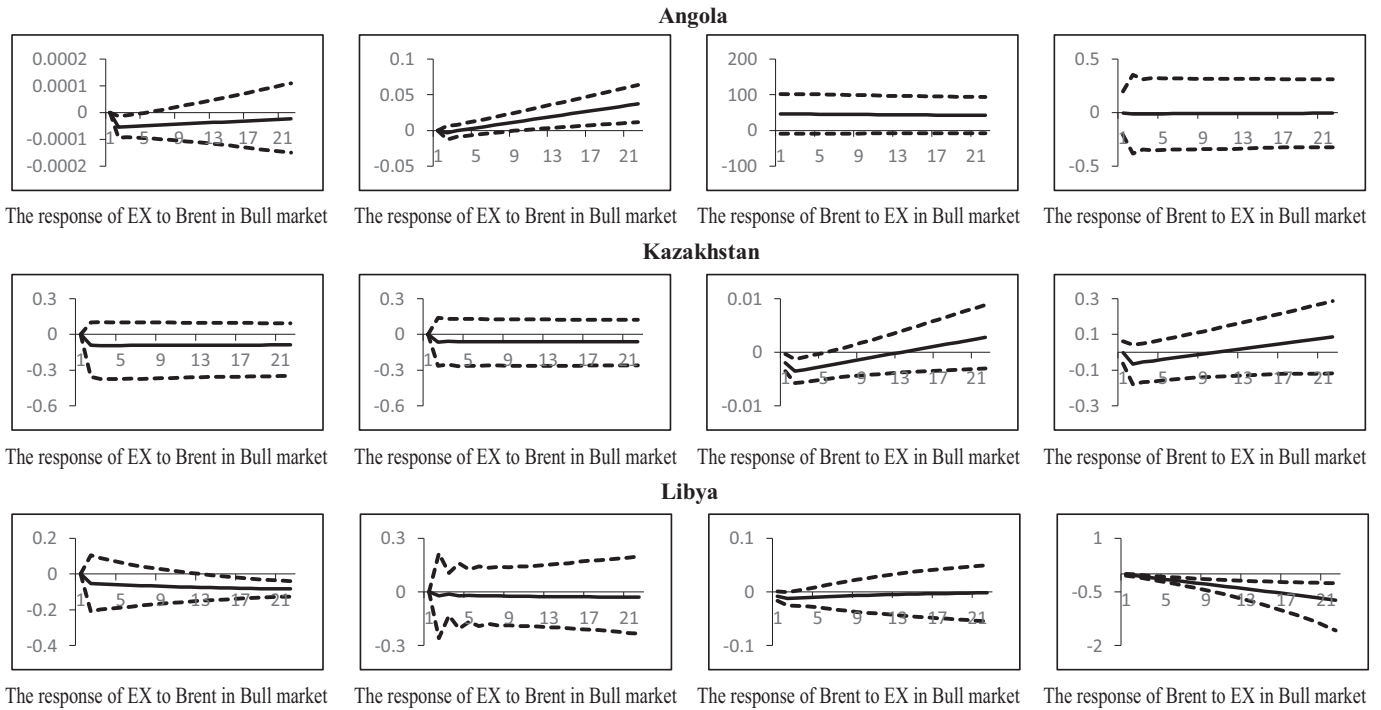*** Represents significance at the 1% level.

Table 7a
Estimation results for countries with soft pegged exchange rate arrangement (using MS-VECM model).

Countries	Variables	Bull market					Bear market					P11	P22	Likelihood
		Intercept	Exchange rate	Oil	ECT	Σ	Intercept	Exchange rate	Oil	ECT	Σ			
Angola	Exchange rate	−0.0003 (0.0016)	0.0002*** (0.0001)	−0.0000** (0.0001)	−0.0000 (0.0000)	0.0000	−0.9043** (0.3625)	−0.2092*** (0.0162)	−0.0056 (0.0070)	−0.0003*** (0.0001)	0.2386	0.7104	0.7092	−11,857.597
	Oil	1.8790 (1.2997)	−0.0020 (0.2214)	−0.0049 (0.0251)	0.0006 (0.0004)	3.6602	0.9166 (1.4411)	−0.0152 (0.2285)	0.0381** (0.0168)	0.0003 (0.000)	5.2232			
Kazakhstan	Exchange rate	1.9264 (1.2578)	0.0253** (0.0134)	−0.0417 (0.1426)	0.0038 (0.0025)	4.2548	1.0391 (7.2125)	−0.0591 (0.0912)	−0.0713 (0.4020)	−0.0020 (0.0144)	20.6103	0.9726	0.5792	−7053.3382
	Oil	−0.1559** (0.0663)	−0.0019** (0.0009)	0.0104** (0.0042)	0.0003** (0.0001)	0.0144	−3.6898 (5.0340)	−0.0705 (0.1142)	−0.0193 (0.0608)	0.0080 (0.0094)	7.2960			
Libya	Exchange rate	4.5770*** (0.9554)	−0.0307 (0.0265)	−0.0462 (0.1120)	−0.0691*** (0.0147)	1.8622	0.7117 (2.5882)	0.0716* (0.0377)	−0.0255 (0.1905)	−0.0137 (0.0403)	8.3759	0.9014	0.7573	−4353.0444
	Oil	−0.0709 (0.1619)	−0.0047 (0.0040)	0.0147 (0.0113)	0.0010 (0.0025)	0.0403	3.1819** (1.3021)	0.0082 (0.0254)	−0.5646*** (0.0292)	−0.0488** (0.0198)	0.9725			

Note: Σ refers to the standard deviation of each state. Standard deviation statistics are shown in parentheses. The transition probabilities are reported as P11 and P22. ECT represents the error correction terms.

* Represents significance at the 10% level.
** Represents significance at the 5% level.
*** Represents significance at the 1% level.

Table 7b
Estimation results for countries with soft pegged exchange rate arrangement (using VAR model).

Countries	Variables	Intercept	Exchange rate	Oil	Likelihood
Iraq	Oil	−0.0042 (0.0387)	−0.0004 (0.0026)	0.01780 (0.0172)	−21,508.313
	Exchange rate	0.2438 (0.2598)	−0.001 (0.01721)	0.0257 (0.1154)	
Azerbaijan	Oil	−0.0041 (0.0401)	0.0073 (0.0435)	0.0210 (0.0190)	−9712.247
	Exchange rate	0.0163 (0.0175)	0.01680 (0.0199)	0.0093 (0.008)	
Saudi Arabia	Oil	0.009 (0.0353)	2.1757 (1.4135)	0.0179 (0.0157)	179.788
	Exchange rate	0.0002 (0.0004)	−0.0139 (0.0157)	−0.0008*** (0.0002)	
Kuwait	Oil	0.010 (0.0353)	−0.3289 (0.2130)	0.0164 (0.0157)	−7422.65
	Exchange rate	0.0013 (0.0026)	−0.1958*** (0.01539)	−0.0048*** (0.0011)	
Qatar	Oil	0.01137 (0.01038)	−0.0084 (1.5205)	0.0172 (0.0157)	873.584
	Exchange rate	0.0002 (0.0003)	−0.4280*** (0.0142)	0.0001 (0.0001)	
Iran	Oil	0.00864 (0.0370)	−0.0062 (0.0133)	0.0213 (0.01720)	−17,323.664
	Exchange rate	0.0785* (0.0456)	−0.01220 (0.0164)	−0.00293 (0.0164)	
Venezuela	Oil	−0.0495 (0.0442)	153.2672 (256.9211)	0.0562** (0.0258)	7960.618
	Exchange rate	2.52e−06 (4.44e−06)	−0.0003 (0.0258)	−7.07e−07 (2.59e−06)	

Note: Standard deviation statistics are shown in parentheses.
* Represents significance at the 10% level.
** Represents significance at the 5% level.
*** Represents significance at the 1% level.

in both regimes for all the countries except for Russia in the bear market. Overall, only few studies have examined the effect of exchange rate on the oil market of oil-exporting countries with managed floating exchange arrangements. Furthermore, the empirical work for the comparative analyses of developed countries is limited. This study particularly extends the existing literature by offering comparative analyses and providing economic explanations behind the empirical results.

5.4. Soft-pegged exchange rate arrangement

A no-causality is expected between oil prices and exchange rates in countries with strong restrictions on their respective exchange rates. This study takes the initiative to examine whether strong interventions can completely eliminate the causality between exchange rates and oil prices.

Given the stringent controls on exchange rate under the soft-pegged exchange arrangement system, the variations of exchange rate are too small to obtain statistically valid results for most of the countries selected in this study. Most of the estimation results in Tables 7a and 7b are statistically insignificant, and the impulse response graphs in Fig. 6(a) and (b) are mostly divergent. Neither long-term causality nor short-term relationship between oil prices and exchange rates is observed for most of the oil-exporting countries that implement strict regulations on their bilateral exchange rates. However, some useful inferences can be derived from the results for Kazakhstan, Kuwait, and Saudi Arabia. For Kazakhstan, the MS-VECM results in Fig. 6(a) suggest the Kazakhstani tenge has a long-term negative impact on oil prices in bear markets. Table 7b reports the significant negative coefficient of exchange rate and oil price in bear markets, suggesting that oil price is affected by the shocks of Kazakhstani tenge in the short term. For Kuwait, the results in both Table 7b and Fig. 6(b) estimated by the VAR model show a small bi-directional negative relationship between the two series in the short term. The largest oil-exporting countries,
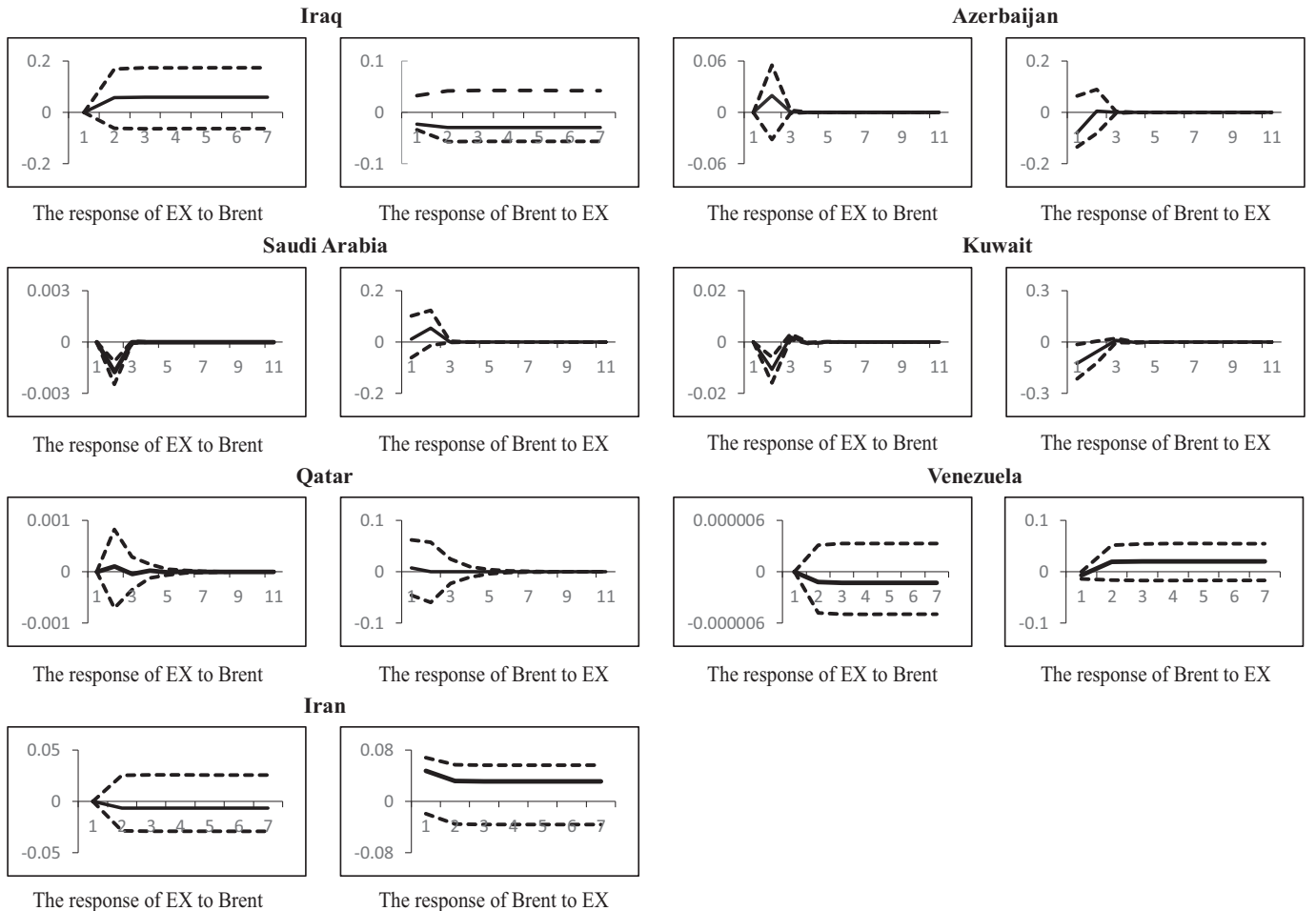
(a). Regime-dependent Impulse Response for Countries with Soft Pegged Exchange Rate Arrangement (Using MS-VECM model)

Angola

| The response of EX to Brent in Bull market | The response of EX to Brent in Bull market | The response of Brent to EX in Bull market | The response of Brent to EX in Bull market |

Kazakhstan

| The response of EX to Brent in Bull market | The response of EX to Brent in Bull market | The response of Brent to EX in Bull market | The response of Brent to EX in Bull market |

Libya

| The response of EX to Brent in Bull market | The response of EX to Brent in Bull market | The response of Brent to EX in Bull market | The response of Brent to EX in Bull market |

(b). Impulse Response for Countries with Soft Pegged Exchange Rate Arrangement (Using VAR model)

Iraq　　　　　　　　　　　　　　　　　　**Azerbaijan**

| The response of EX to Brent | The response of Brent to EX | The response of EX to Brent | The response of Brent to EX |

Saudi Arabia　　　　　　　　　　　　　**Kuwait**

| The response of EX to Brent | The response of Brent to EX | The response of EX to Brent | The response of Brent to EX |

Qatar　　　　　　　　　　　　　　　　　**Venezuela**

| The response of EX to Brent | The response of Brent to EX | The response of EX to Brent | The response of Brent to EX |

Iran

| The response of EX to Brent | The response of Brent to EX |

Fig. 6. (a). Regime-dependent impulse response for countries with soft pegged exchange rate arrangement (using MS-VECM model). (b). impulse response for countries with soft pegged exchange rate arrangement (using VAR model). Note: EX represents the shocks of exchange rate price, and Brent represents the shocks of Brent oil price.
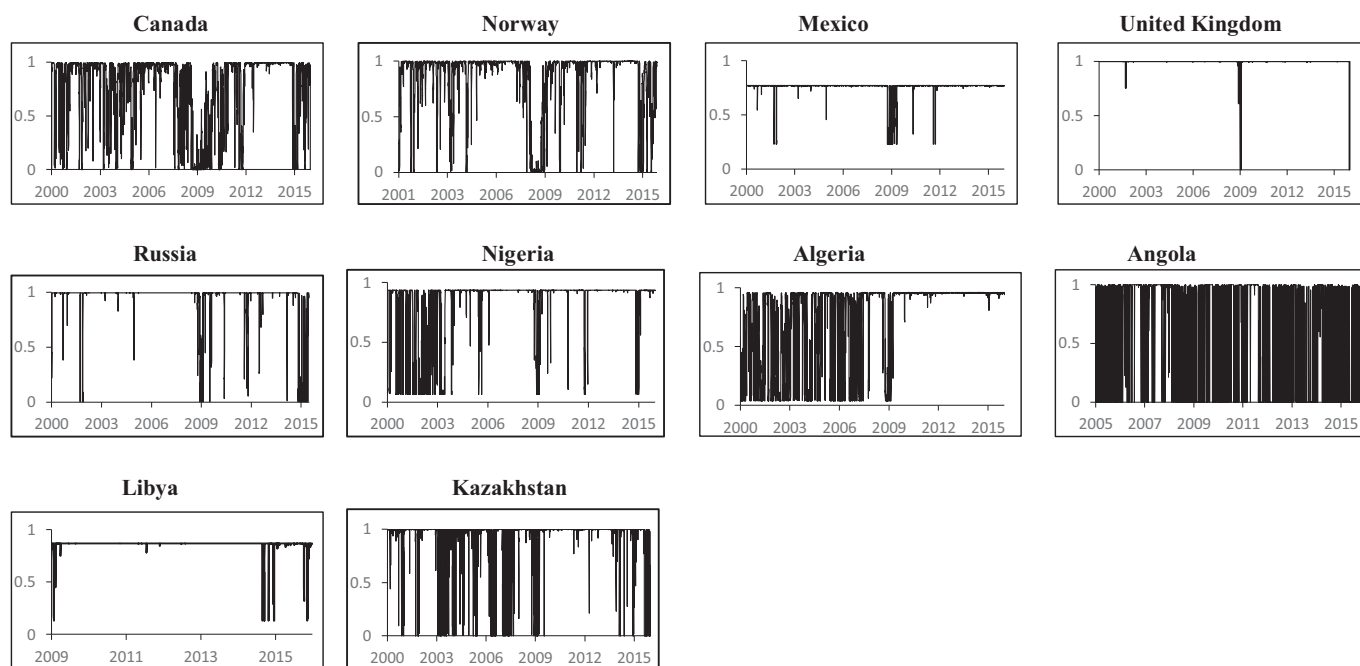
Fig. 7. Smoothed probabilities in bull market using oil prices denominated in domestic currency. Note: The smoothed probabilities in bull market for Canada, Norway and Kazakhstan are calculated by the MS-VECM model, and the results for the other countries are estimated by the MS-VAR model.

including Saudi Arabia, opt to strictly control their exchange rates. Nonetheless, we find very small but significant responses of exchange rates toward oil prices.

In summary, the results for the countries with soft-pegged exchange arrangements imply that tight restrictions weaken or even eliminate the causality between exchange rates and oil prices. For countries such as Azerbaijan, Libya, and Kazakhstan, long-term or short-term causal relationships exist between exchange rates and oil markets. These countries have essentially adopted exchange rate policies because their economies are heavily dependent on the oil industry or oil prices. The high dependence on the oil industry (or oil prices) can easily trigger strict intervention policies on exchange rates, a scheme that can mitigate but not eliminate the relationship between exchange rates and oil prices.

6. Further analysis

6.1. Using oil prices denominated in domestic currency

Oil prices denominated in the domestic currency are directly relevant to local consumers and producers. Thus, we convert the dollar price of oil to the domestic currency price and re-investigate the relationship between exchange rate and the domestic currency price of oil. We first implement unit root and co-integration tests and find that the results are the same as those previously discussed, except for Libya in which a long-term relationship ceases to exist. AIC and BIC statistics, combined with the smoothed probabilities estimated by the MS-VAR or MS-VECM model (Fig. 7), are used to determine whether the non-linear MS structure should be incorporated.[17]

The smoothed probabilities for Mexico, UK, and Libya differ dramatically from Fig. 2 (oil price denominated in US dollar) and Fig. 7 (oil price denominated in the domestic currency). The smoothed probabilities in Fig. 7 seldom switch from State 1 to State 0, thus suggesting that linear VAR modeling is appropriate for Mexico, UK, and Libya. The finding can

be attributed to these countries being insulated to some extent from the movements of external crude oil prices. The domestic currency prices of oil in these countries do not co-move closely with external crude oil prices, which suggest somewhat stable characteristics. On the basis of this finding, exchange rates do not have a non-linear relationship with the more-stable domestic currency prices of oil.

Fig. 8, which presents the relationship between exchange rates and domestic currency prices of oil for countries with free-floating exchange rate arrangements, somewhat differ from those shown in Fig. 4. First, the bidirectional (or unidirectional) long-term effect between oil prices and exchange rates has become small or statistically insignificant in Fig. 8(a) for Canada and Norway. The response of oil price measured by domestic currency toward the exchange rate in Canada (Fig. 8(a)) is weakened in both bull and bear markets. A similar result is observed for Norway in the bear market. As shown in Fig. 8(b), the responses of oil prices measured by domestic currencies toward the exchange rates in Mexico and UK in the short term have become insignificant or small, whereas the effects of oil prices on exchange rates have weakened for Mexico and became insignificant for UK. Overall, for countries with free-floating exchange rate arrangements, the exchange rate remains related to oil price when the dollar-denominated oil price is replaced with the domestic currency-denominated oil price, but this relationship is weakened in the both the short and long terms. One possible explanation is the insulation of countries with free-floating exchange rate arrangements from external crude oil price movements to some extent. In addition, these countries always sell their crude oil directly for dollars while maintaining stable exchange rates (Fig. 1). Accordingly, from the viewpoint of local consumers and producers, the instability of domestic currency-denominated oil price is mainly driven by global oil price. Local consumers and producers will likely be more concerned with global oil prices than with the domestic currency price of oil.

Fig. 8(c) shows the new results for countries with managed floating exchange rate arrangements. The main difference is related to the impact of oil prices on exchange rates, which have now become much stronger in bear markets. On this basis, we can therefore speculate that consumers and producers will more likely to convert their dollars into domestic currency prices when making decisions, and

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[17] Given the page limitation, the results of unit root, co-integration, and AIC (or BIC) are not reported in this paper.
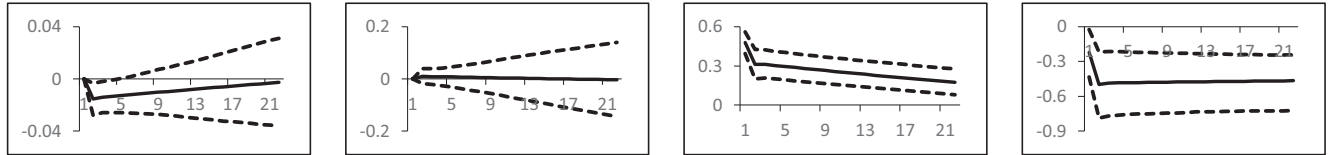
Fig. 8. Regime-dependent impulse response using oil prices denominated in domestic currency. (a). The results for countries with free floating exchange rate arrangement (using MS-VECM model). (b). The results for countries with free floating exchange rate arrangement (using VAR model). (c). The results for countries with managed floating exchange rate arrangement (using MS-VAR model). (d). The results for countries with soft pegged exchange rate arrangement. Note: EX represents the shocks of exchange rate price, and OilDC represents the shocks of oil price measured by domestic currency.

(d). The Results for Countries with Soft Pegged Exchange Rate Arrangement

Following two countries using MS-VECM model
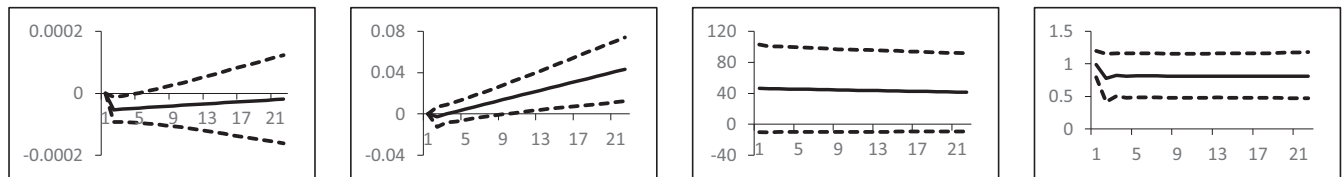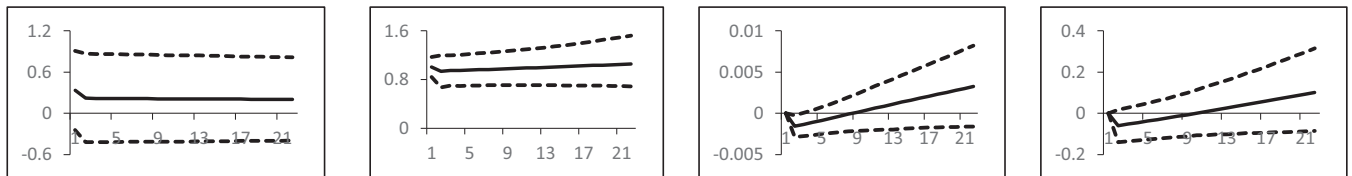
Angola

| The response of EX to OilDC in Bull market | The response of EX to OilDC in Bear market | The response of OilDC to EX in Bull market | The response of OilDC to EX in Bear market |

Kazakhstan

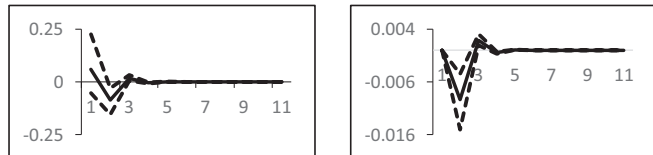| The response of EX to OilDC in Bull market | The response of EX to OilDC in Bear market | The response of OilDC to EX in Bull market | The response of OilDC to EX in Bear market |

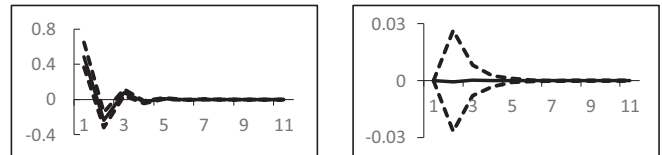**Following three countries using MS-VECM model**

Kuwait   **Libya**

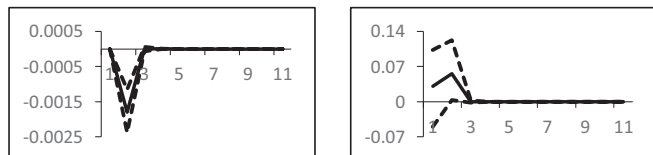| The response of EX to OilDC | The response of OilDC to EX | The response of EX to OilDC | The response of OilDC to EX |

Saudi Arabia

| The response of EX to OilDC | The response of OilDC to EX |

Fig. 8 (*continued*).

they sophisticated recognize the decline in the domestic prices of oil as being greater than that of external crude oil prices during bear market conditions. The second new finding is related to the short-term positive significant effect of oil prices on exchange rates for all three countries in the bear market. Given the volatility of exchange rates in bear markets, consumers and producers will likely expect the domestic currency prices of oil to become more unstable than the global oil prices. Unstable domestic oil prices easily trigger inflation and exchange rate depreciation. Finally, an interesting new result involves the effect of exchange rates on domestic oil prices. The effect becomes small or insignificant in the bull market, but it is strong in the bear market, for the three countries. An economic explanation is as follows. Consumers and producers both recognize that government interventions will stabilize exchange rates in bull markets but not in bear markets. Thus, the impact of exchange rates on the domestic currency prices of oil is reduced in bull markets but widened in bear markets.

Finally, for countries with soft-pegged exchange rate arrangements, a relatively strong impact of domestic currency prices of oil on exchange rates is observed (Fig. 8(d)), albeit the effect is a comparatively small for Kazakhstan. For Libya, the response of domestic currency prices of oil toward the exchange rate is significant but irregular. In this case, the tight regulation initially could not eliminate the relationship. Consumers and

producers then pay more attention on domestic currency prices, which enhances the relationship between exchange rate and global oil price (Fig. 6(a)). The effects of domestic currency prices of oil on exchange rates are lowered for Kuwait and Saudi Arabia. The results for the other countries are the same as those provided in Section 5.4; that is, no relationship exists between exchange rates and oil prices.

Overall, the new findings imply that consumers and producers of crude oil have sufficiently sophisticated decision-making capabilities and will likely convert the oil prices from dollar denomination to domestic currency denomination in practice. They will also likely learn that the exchange rates in countries with (developed economies) free-floating exchange rate arrangements are stable, and the domestic currency prices of oil are more stable than the global oil price. The exchange rates in countries with managed floating exchange rate arrangements (i.e., developing economies, but highly dependent on the oil industry) are unstable. When faced with declining global oil prices (bear markets), the domestic currency prices of oil decrease become more apparent. Thus, when the domestic currency price is adopted during the decision making of consumers and producers, such behavior will likely weaken the relationships between the two series for countries with free-floating exchange rate arrangements. By contrast, comparatively strong effects in bear markets will likely exist in countries with managed floating exchange rate arrangements.

Table 8
The results of breakpoint date.

	Date 1	Date 2	Date 3	Date 4	Date 5
Oil	2002/09/03	2005/01/12	2007/06/01	2010/12/20	2013/08/08
Canada	2003/04/28	2005/09/02	2008/01/30	2010/07/06	2013/08/08
Norway	2003/03/25	2006/04/25	2008/10/02	2011/01/10	2013/10/02
Mexico	2002/12/24	2005/05/26	2008/09/29	2011/03/01	2013/08/08
UK	2003/09/19	2006/06/08	2008/09/29	2011/03/09	2013/08/08
Russia	2002/04/22	2004/08/05	2006/11/16	2009/03/25	2013/03/04
Nigeria	2002/07/08	2006/06/14	2008/10/30	2011/03/23	2013/08/20
Algeria	2003/11/04	2006/05/01	2008/10/09	2011/03/08	2013/08/13
Angola	2005/08/22	2006/04/12	2014/11/03	2011/09/14	2014/05/14
Libya	2010/09/28	2011/10/21	2012/11/13	2013/12/02	2014/12/16
Kazakhstan	2003/12/23	2006/04/19	2008/12/01	2011/04/11	2013/08/29

Notes: The results of breakpoint are estimated by the model of Bai and Perron (2003) and help to classify the bull and bear market.

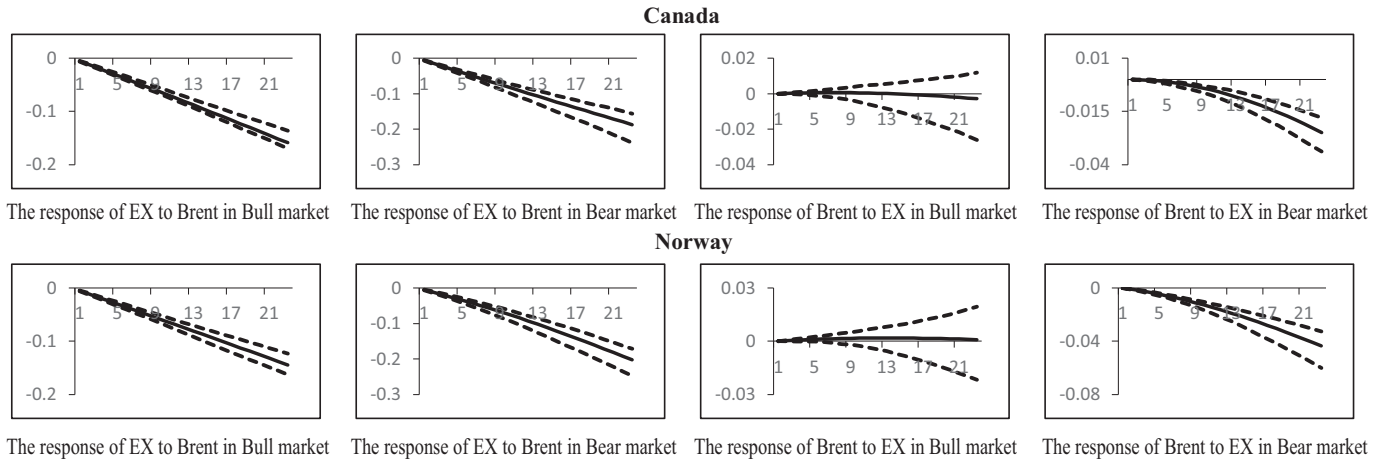### 6.2. Results estimated by piecewise VAR/VECM models

We consider exogenous switching as an alternative to the endogenous switching models. In particular, we adopt the structural breakpoint tests of Bai and Perron (2003) to identify the switching points and then conduct simple piecewise VAR or VECM modeling to re-examine the previously discussed main findings.

The statistics of AIC and RSS estimated with the Bai and Perron (2003) method derives five breakpoints for oil price and four or five

breakpoints for each exchange rate. The two sets of breakpoints overlap and resemble one other. We therefore report the coarser set with five breakpoints in Table 8. Two breakpoints for oil price and exchange rate have occurred around the same period, namely, one on December 2010 and the other on August 2013. As shown in Fig. 1, oil prices and exchange rates have both risen from December 2010 to August 2013 and then fell after August 2013. Thus, we classify the regimes for oil price and exchange rate as belonging to the bull market from December 2010 to August 2013 and to the bear market from August 2013 to December 2015. On the basis of this classification, we split the data into two sub-samples (2011.1–2013.7 vs. 2013.8–2015.12) and estimate the VAR or VECM model for each sub-sample to investigate the relationship between exchange rate and oil in different regimes.

As shown in Fig. 9(a), the new results for Canada and Norway differ from the previous findings in that the oil price now significantly affects the Canadian dollar and the Norwegian krone in the bear market (2013.8–2015.12). This new finding contrasts the previous conclusion that oil price does not affect the exchange rates in these two oil-exporting countries. Moreover, this finding indicates that MS-VAR and MS-VECM have certain limitations. Piecewise linear VAR or VECM offers competitive alternative modeling for robustness check. The sub-sample results of VECM for Canada and Norway further support the findings by the MS-VECM model that exchange rates have significant effects on the global oil price in both bear and bull markets, although the effect is smaller in the latter. We also estimate the linear VAR or VECM model

(a). Impulse Response for Countries with Free Floating Exchange Rate Arrangement (Using VECM model for Subsample)

Canada

The response of EX to Brent in Bull market   The response of EX to Brent in Bear market   The response of Brent to EX in Bull market   The response of Brent to EX in Bear market

Norway

The response of EX to Brent in Bull market   The response of EX to Brent in Bear market   The response of Brent to EX in Bull market   The response of Brent to EX in Bear market

(b). Impulse Response for Countries with Managed Floating Exchange Rate Arrangement (Using VAR model for Subsample)

Russia

The response of EX to Brent in Bull market   The response of EX to Brent in Bear market   The response of Brent to EX in Bull market   The response of Brent to EX in Bear market

Nigeria

The response of EX to Brent in Bull market   The response of EX to Brent in Bear market   The response of Brent to EX in Bull market   The response of Brent to EX in Bear market

Fig. 9. (a). Impulse response for countries with free floating exchange rate arrangement (using VECM model for subsample). (b). Impulse response for countries with managed floating exchange rate arrangement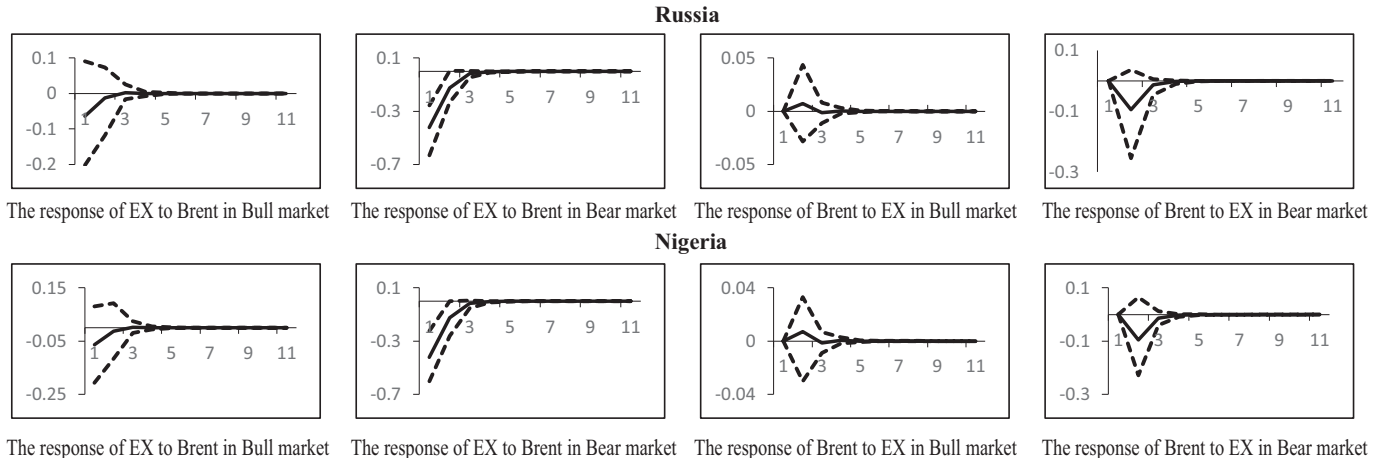 (using VAR model for subsample). Note: EX represents the shocks of exchange rate price, and Brent represents the shocks of Brent oil price. The bull market is during December 2010 to August 2013 and the bear market is during August 2013 to December 2015.

for the other countries. As shown in Fig. 9(b), the findings are similar to the results obtained by MS models.[18]

7. Conclusions and policy implications

Although many studies have investigated the causality between exchange rates and oil prices for oil-exporting countries, only a few of them have examined how the exchange rate restrictions of developing oil-exporting countries may distort the theoretical relationship between exchange rates and oil prices, which is developed under the assumption of free-floating exchange rates. This paper provides the comparative analyses for discussing the differences in the oil–exchange rate causality for countries with free-floating, managed floating, and soft-pegged exchange rate arrangements.

On the basis of MS-VAR (VAR) and MS-VECM modeling, this paper presents several interesting findings. First, the benchmark results for countries with free-floating exchange rate arrangements show the significant negative response of exchange rates toward the oil market in the short term, which verifies the portfolio channel argument, and the significant negative response of the oil market toward exchange rates, which verifies the denomination channel argument. The results also demonstrate the non-linear causality between exchange rate and oil prices given that the correlations tend to increase in bear markets rather than in bull markets in both the long term (Canada and Norway) and the short term (Mexico and UK). Second, while interventions on the exchange rate market matter, the policy effect is limited. When government restriction is enhanced, the correlation between exchange rates and the oil market decreases. However, regardless whether the scheme is a managed exchange rate or a pegged exchange rate, the causal relationship in either direction cannot be completely eliminated. Third, for countries with managed floating exchange rate arrangements, we find no response of exchange rates toward oil prices in bull markets, but a significant response is observed in bear markets. This finding can be attributed to the asymmetric power of central banks in controlling appreciation pressure and preventing depreciation pressure.

When the oil price is denominated in the domestic currency instead of the US dollar, the relationship between exchange rates and domestic currency prices of oil are weakened both in the short and long terms for

countries with free-floating exchange rate arrangements. Meanwhile, for countries with managed floating exchange rate arrangements, the impact of oil prices on exchange rates becomes much stronger in bear markets, whereas the effect of exchange rates on oil prices is reduced or becomes insignificant in bull markets but strengthened in bear markets. Finally, a new and stronger impact of oil prices on exchange rates for selected countries with soft-pegged exchange rate arrangements (Libya) is observed, although the feedback effect is smaller for Kuwait and Saudi Arabia.

The results provide practical and useful insights for policy makers of developing oil-exporting countries. In the long term, governments should upgrade or transform their respective economic structures to reduce their oil dependency. Such countries may reform their exchange rate arrangements to become free floating. In addition, for all countries with managed floating exchange rate arrangements and for some economies with soft-pegged exchange rate arrangements (Kazakhstan, Kuwait, and Saudi Arabia), emergency policies should be institutionalized to alleviate the spillover effects of oil crises and prevent exchange rate crises in the short term.

This study provides a number of useful suggestions for investors when making decisions related to bull or bear markets. Investors need to consider the exchange rate policy and the market state of their respective countries. For example, in bull market periods, the exchange rates of managed-floating countries and oil prices should be handled simultaneously to reduce investment risks. By contrast, investing in exchange rate markets during bear market periods is much riskier. Even if the governments of developing oil-exporting countries attempt to appreciate their respective local currencies, the associated policy may not be as effective as expected.

Appendix A. Smoothed probabilities in bull market for some countries with soft pegged exchange rate arrangement
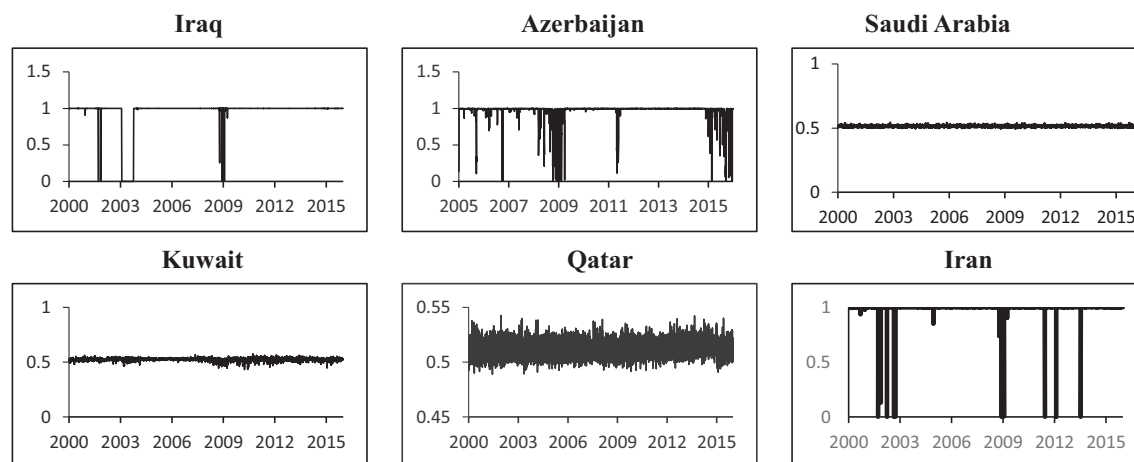
Notes: Even the AIC and BIC of some above countries in Table 4b shows the VAR model should be better than MS-VAR model, we would like to show their unchanged smoothed probabilities to explain a single regime rather than two regimes, and further robust selection of VAR model.

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[18] Due to space limitation, we only report the results for two selected countries with managed floating exchange rate arrangement. The results for other countries are available upon request.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2018.10.017.

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