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**Working Paper**

## Exchange rate movements and fundamentals: Impact of oil prices and the People's Republic of China's growth

ADB Working Paper Series, No. 938

**Provided in Cooperation with:**

Asian Development Bank Institute (ADBI), Tokyo

*Suggested Citation:* Chen, Hongyi; Cao, Shuo (2019) : Exchange rate movements and fundamentals: Impact of oil prices and the People's Republic of China's growth, ADB Working Paper Series, No. 938, Asian Development Bank Institute (ADBI), Tokyo

This Version is available at:

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**ADB Working Paper Series**

**EXCHANGE RATE MOVEMENTS  
AND FUNDAMENTALS: IMPACT  
OF OIL PRICES AND THE PEOPLE'S  
REPUBLIC OF CHINA'S GROWTH**

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Hongyi Chen and Shuo Cao

No. 938  
March 2019

**Asian Development Bank Institute**

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Suggested citation:

Chen, H. and S. Cao. 2019. Exchange Rate Movements and Fundamentals: Impact of Oil Prices and the People's Republic of China's Growth. ADBI Working Paper 938. Tokyo: Asian Development Bank Institute. Available: <https://www.adb.org/publications/exchange-rate-movements-and-fundamentals-impact-oil-prices-prc-growth>

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We thank William Cheung, Charles Engel, Gaofeng Han, Gary Koop, Dimitris Korobilis, Nelson Mark, Andrew Rose, Andrew Tsang, Mike West, Matthew Yiu, and seminar participants at the Hong Kong Institute for Monetary Research, Nankai University, and ADBI Conference on Globalization, Development, Economic and Financial Stability for helpful comments and suggestions, and Ho Ting Fung for assistance in collecting the data. Cao appreciates the research award and grant of the China Postdoctoral Science Foundation, and the financial support and hospitality of HKIMR during his visit. The views expressed in this paper are those of the authors, and do not necessarily reflect those of the Shenzhen Stock Exchange, the CSRC system, the Hong Kong Monetary Authority, Hong Kong Institute for Monetary Research, its Council of Advisers, or the Board of Directors.

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**Abstract**

This paper identifies five factors that can capture 95% of the variance across 39 US dollar exchange rates based on the principal component method. A time-varying parameter factor-augmented vector autoregressive (TVP-FAVAR) model is used to analyze the determinants of movements in these exchange rates, revealing that their impact on global oil prices and the People's Republic of China's growth has increased significantly since 2008. In particular, the variance of US dollar exchange rates has mainly been driven by these two shocks in recent years. The impact of monetary policy shocks on the currency pairs is comparatively small.

**Keywords:** exchange rates, commodity prices, People's Republic of China's growth, monetary policy, factor model, TVP-FAVAR, Bayesian methods

**JEL Classification:** C11, C22, F31, G12

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# 1. INTRODUCTION

This paper demonstrates that the fluctuations of US dollar-based exchange rates can be captured by a low dimension of principal components. We analyze the evolution of exchange rate dynamics and show that the movements in exchange rates can be largely explained by shocks to two fundamentals—global oil prices and growth of the People’s Republic of China (PRC). This finding holds for both commodity and non-commodity currency pairs, extending the results from the previous literature. The explanatory power of economic fundamentals has increased significantly since the 2007–2008 financial crisis because of the rapid rise in uncertainty. We also find that global oil prices are most important during the financial crisis, whereas the PRC’s growth contributes to half of the variance in the past five years.

From a global perspective, Chen and Rogoff (2003) and Chen, Rogoff, and Rossi (2010) indicate that commodity prices are of importance for commodity currencies. When global investors infer economic conditions from commodity price information, the exchange rate movements of non-commodity currencies will also be severely influenced by commodity price changes. The PRC, as the world’s biggest importer of commodities, can affect commodity prices to a large extent from its strong trade linkages, see Frankel (2006).<sup>1</sup> Yin and Han (2016) show that macroeconomic factors of the PRC have significant impact on commodity markets. To this end, we are interested in whether the rise of the PRC affects global exchange rate dynamics, especially after the financial crisis. The changing exchange rate dynamics are captured by a novel methodology—the time-varying parameter factor-augmented vector autoregressive (TVP-FAVAR) model. It follows from the evidence of Chen, Rogoff, and Rossi (2010) and Byrne, Korobilis, and Ribeiro (2016) that there are potential structural breaks in the exchange rate structure as observed empirically.<sup>2</sup> Moreover, this approach is helpful in modeling potential stochastic trends that can induce the unit root behavior of exchange rates indicated in Engel and West (2005). By allowing for time-varying parameters, the approach provides informative implications about economic fundamentals and economic regimes.

Our analysis is related to the present-value model proposed in the seminal paper of Engel and West (2005). When market participants price fundamentals into the exchange rate through its anticipated impact on future exchange rate values, the nominal exchange rate tends to be sensitive to shocks to current global market conditions. Therefore, the uncertainty in fundamentals may drive global exchange rates to comove even before a real effect materializes. If the PRC’s growth, for example, is an important economic indicator monitored by investors, the shocks to this indicator can potentially cause global fluctuations in exchange rates.

In order to estimate the true dynamics, our approach embodies rich information implied in exchange rates that is orthogonal to fundamentals. Building upon the factor structure in Engel, Mark and West (2015), we employ the principal component method to identify five latent global factors that capture most of the variance of 39 currencies from 1995 to 2015. In a TVP-FAVAR we jointly model the dynamics of fundamentals and exchange rate latent factors, which reveals the time-varying patterns of global exchange rate drivers. We examine the extent to which the global oil prices and the PRC’s growth contribute to the movements of exchange rates over time. The uncertainty in oil prices

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<sup>1</sup> See also Hummels (2011) for a discussion about the PRC’s growing role in world trade.

<sup>2</sup> Byrne, Korobilis, and Ribeiro (2017) further reveal that parameter uncertainty is a key obstruction to the predictive ability of exchange rate models.

and the PRC's growth has increased rapidly since the financial crisis, and the exchange rate fluctuations across economies or regions are essentially captured by the shocks to these two fundamentals from 2005 to 2015.<sup>3</sup> From 2010 to 2015, these two variables account for more than 65% of the exchange rate variance on average. The surprisingly high explanatory power of these shocks has structural interpretations. The effects of global oil prices are consistent with the purchasing power parity (PPP) model, and we find that the exchange rates tend to adjust more quickly to the oil prices in the latest period. Moreover, we find that influence of the PRC's growth increases sharply in 2008 and dominates other factors, which is new to the literature. In addition to the trade channel, unexpected changes in the PRC's growth potentially affect global investors' demand for currency assets, causing quick responses and comovement of related currency pairs.

The remainder of the paper is structured as follows. Section 2 describes our model and the estimation. Section 3 describes the data and reports the results. Specifically, Section 3.2 discusses the economic content of the global latent factors. Sections 3.3 and 3.4 analyze the time-varying patterns of the fundamentals of global exchange rates. In Section 4 we conduct robustness checks. Section 5 concludes.

## 2. METHODOLOGY

As suggested by Bernanke, Boivin, and Eliasch (2005), incorporating information not reflected in standard macro fundamentals is important to properly identify the underlying transmission mechanism. Therefore, we aim to consider a system with richer information, which potentially provides a more comprehensive and coherent picture of exchange rate dynamics. In the following, we describe a two-step procedure to properly extract different layers of information, particularly from the cross section of exchange rates.

### Extraction of Cross-sectional Information

In the first step, we identify a set of linear latent factors for the log nominal exchange rate  $s_{t,i}$  of economy  $i$  at time  $t$ , from the below equation:

$$s_{t,i} = \alpha_i' I_t + \epsilon_t^i,$$

where  $I_t$  collects the common factors across economies or regions,  $\alpha$  are factor loadings, and  $\epsilon_t^i = \beta_i' I_{t,i}$  denotes the economy-specific variation. The above representation is consistent with the factor structure specified in Engel, Mark, and West (2015).<sup>4</sup> We can identify the common factors  $I_t$  using the principal component method proposed by Stock and Watson (2002).

The identified factors  $I_t$  include the information of both observable fundamentals and unobservable variables. As we would like to focus only on the explanatory power of a specific set of observable fundamentals  $f_t$ , in the second step we construct a factor-augmented vector autoregressive model that incorporates both  $f_t$  and  $I_t$ .

<sup>3</sup> The exposure to additional exchange rate volatility induced by the PRC's growth or oil prices is linked to more recent hedging activities (for example, New York Fed 2016 data) in exchange rate derivatives, like Forwards, FX Swaps, FX options, currency swaps; we thank William Cheung for pointing this out.

<sup>4</sup> We can establish a linear relationship between the log nominal exchange rate and a set of latent global factors from a present-value model, in which factor loadings are mapped from structural parameters and the VAR parameters, see Appendix 3 for details.

## The Factor-augmented Time-series Dynamics

We proceed to the second step with a reduced-form equation that describes the exchange rate movements driven by fundamentals  $f_t$  and latent factors (principal components)  $I_t$ :

$$s_{t,i}^G = \alpha_i^{*'} \begin{bmatrix} f_t \\ I_t \end{bmatrix}. \quad (1)$$

With Equation (1), we can evaluate the extent to which structural shocks to  $f_t$  can explain movements in exchange rates. We achieve this goal by estimating the joint dynamics with fundamentals in a factor-augmented vector autoregressive model (FAVAR, see Bernanke, Boivin and Elias (2005)), as they suggest a rich information set is helpful in revealing the true dynamics. For now, we assume the variables in the system are stationary, but we will discuss the nonstationary case and motivate a novel method in the next section. Accordingly, the joint dynamics of  $(f_t, I_t)$  are given by

$$\begin{bmatrix} f_t \\ I_t \end{bmatrix} = c + \Phi(L) \begin{bmatrix} f_{t-1} \\ I_{t-1} \end{bmatrix} + v_t, \quad (2)$$

where  $c$  is vector of constants,  $\Phi(L)$  is a conformable lag polynomial of finite order  $d$ , and the error term  $v_t$  is mean zero with covariance matrix  $Q$ .

### 2.1 TVP-FAVAR

As indicated by Chen, Rogoff, and Rossi (2010), it is important to allow for the time variability in exchange rate dynamics. More importantly, Engel and West (2005) suggest that at least some of the nominal exchange rates have unit roots, so the nonstationary behavior of exchange rate determinants may not be well captured in a constant-parameter FAVAR model. These findings are echoed by Baillie and Bollerslev (1989), who present strong evidence that stochastic trends are a source of the unit root behavior of exchange rates. Therefore, we extend Equation (2) to a time-varying parameter (TVP) FAVAR model, in which stochastic intercepts are explicitly specified:

$$\begin{bmatrix} f_t \\ I_t \end{bmatrix} = c_t + \Phi_t(L) \begin{bmatrix} f_{t-1} \\ I_{t-1} \end{bmatrix} + v_t,$$

where  $c_t$  are the stochastic intercepts, which are useful in capturing potential unit root behavior of exchange rate determinants. This novel model has a state space representation and can be estimated by the Kalman filter.<sup>5</sup> For better description of the state space structure, we rewrite the  $p$ -lag TVP-FAVAR in the following compact form

$$Z_t = X_t \beta_t + v_t,$$

where  $Z_t = [f_t, I_t]'$ ,  $f_t$  is a  $m \times 1$  vector of fundamentals,  $I_t$  is a  $q \times 1$  vector of latent factors,  $X_t = I_n \otimes [Z'_{t-1}, \dots, Z'_{t-p}]$  for  $n = m + q$ ,  $\beta_t = [c_t, \text{vec}(B_{1t})', \dots, \text{vec}(B_{pt})']'$  is a vector summarizing all VAR coefficients and  $v_t \sim N(0, \Sigma_t)$  with  $\Sigma_t$  an  $n \times n$  covariance matrix.<sup>6</sup> This regression-type equation is completed by describing the law of motion

<sup>5</sup> Chang, Miller, and Park (2009) show that stochastic trends in a state space model can be plausibly estimated using the Kalman filter.

<sup>6</sup> In this paper we use one lag, i.e.  $p = 1$ , following Engel, Mark, and West (2015). As the factor system is persistent and has the Markov property, our findings are robust to other lag selections.



of the time-varying parameters  $\beta_t$  and  $\Sigma_t$ . For  $\beta_t$  we follow the standard practice in the literature from Primiceri (2005) and consider random walk evolution for the VAR coefficients,

$$\beta_{t+1} = \beta_t + \mu_t,$$

based upon a prior  $\beta_0$  discussed below, and  $\mu_t \sim N(0, Q_t)$ . Following Koop and Korobilis (2013) we set  $Q_t = (\Lambda^{-1} - 1)cov(\beta_{t-1} | \mathcal{D}_{t-1})$  where  $\mathcal{D}_{t-1}$  denotes all the available data at time  $t - 1$  and scalar  $\Lambda \in (0, 1]$  is a “forgetting factor”, discounting older observations.

The covariance matrix  $\Sigma_t$  evolves according to a Wishart matrix discount process (Prado and West (2010)) of the form:

$$\begin{aligned} \Sigma_t &\sim iW(S_t, n_t), \\ n_t &= \delta n_{t-1} + 1, \\ S_t &= \delta S_{t-1} + f(v_t' v_t), \end{aligned}$$

where  $n_t$  and  $S_t$  are the degrees of freedom and scale matrix, respectively, of the inverse Wishart distribution,  $\delta$  is a “decay factor” discounting older observations, and  $f(v_t' v_t)$  is a specific function of the squared residuals of our model.

The VAR system allows for the interdependence of endogenous variables. The time-varying nature of our method allows us to compute different variance decomposition and impulse response functions at different points in time. We therefore can analyze the evolution of exchange rate dynamics by identifying structural shocks of fundamentals. We employ the standard Cholesky identification scheme to identify orthogonal structural shocks. Our baseline specification of VAR consists of six fundamentals (global oil prices, the PRC’s industrial production (IP), the PRC’s import, the US effective federal fund rate, and short rates of the euro area and Japan) and five exchange rate factors collected in  $I_t$ , and we orthogonalize shocks recursively in that order. This ordering allows us to pin down exactly how much variance of exchange rates is driven by shocks to fundamentals  $f_t$  without double counting the same information incorporated in  $I_t$ .

The identified structural shocks of these macro fundamentals allow us to analyze at each point in time the relative importance of these macroeconomic sources in driving the exchange rate movements. The variance decomposition of these structural shocks is given by

$$Var(s_{t,i}^G) = \alpha_{i,f}' Var(f_t) \alpha_{i,f} + \alpha_{i,I}' Var(I_t) \alpha_{i,I}, \quad (3)$$

where  $\alpha_{i,f}$  and  $\alpha_{i,I}$  are obtained by regressing exchange rates on  $(f_t, I_t)$  according to Equation (1).

In summary, we specify a FAVAR with drifting coefficients, which allows for model structural instability and regime changes in the joint dynamics of the exchange rate factors and the fundamentals. We also allow for stochastic volatility, so an unconditional fat tail distribution in the data is taken into consideration. Here we extend the methodology of Koop and Korobilis (2013) and conduct an efficient estimation scheme to provide accurate results while largely speeding up the estimation of our large TVP-FAVAR (11 variables). This method is computationally convenient as no Markov Chain Monte Carlo (MCMC) is needed. We use what is known as a “forgetting factor” or “decay factor” to discount the previous information when updating the parameter

estimates; detailed information of our empirical methodology can be found in Appendix 2.

### 3. DATA AND RESULTS

#### 3.1 Data Description

Our full sample is monthly data from 1995:01 to 2015:12, and we use the data before 2001:01 as the training sample to form the prior distributions.<sup>7</sup> Our exchange rate data and global oil prices are from the Bloomberg Database (end-of-month), which includes 37 currencies in the following economies or regions: Argentina; Australia; Brazil; Canada; Switzerland; Chile; the PRC; Colombia; Czech Republic; Denmark; Egypt; Eurozone; the UK; Ghana; Hong Kong, China; Hungary; Indonesia; India; Iceland; Japan; Kenya; the Republic of Korea; Mexico; Malaysia; Norway; New Zealand; Peru; the Philippines; Poland; the Russian Federation; Sweden; Singapore; Thailand; Turkey; Taipei, China; Central Africa; and South Africa. In addition, we include gold and IMF special drawing rights (SDR). For all currencies we use the US dollar as the base currency.

The year-on-year growth rates of the PRC industrial production and import are from the CEIC Database, which is also in monthly frequency. The US effective federal fund rate (shadow rate) is from the Federal Reserve Bank of Atlanta, which is computed based on the method proposed by Wu and Xia (2016). The shadow short rates (SSR) of the euro area and Japan are from the Reserve Bank of New Zealand.<sup>8</sup>

#### 3.2 Principal Components

In this section we show that a low dimension of principal components can capture the exchange rate fluctuations in levels. Using the principal component method, the first five global currency factors account for around 95% of the global currency variance.<sup>9</sup> These principal components, extracted by a statistical method, have economic content.

As shown in Figure 1 the first principal component (PC1) strongly correlates with the currencies of most developed economies and is mostly correlated with the SDR value of the US dollar. In general, these economies have relatively sophisticated financial markets and flexible exchange rate regimes. The second factor, in contrast, is highly correlated with emerging market currencies, such as the Turkish lira, Russian ruble, Indonesian rupiah, and Indian rupee. The third factor, in particular, is heavily correlated with the British pound, with a correlation coefficient of 0.89. The last two factors do not have particularly high correlation with any currencies, but they are generally quite important in driving Asian currencies, such as the Japanese yen, Republic of Korean won, and Hong Kong dollar. The results of all currencies are reported in Table 1.<sup>10</sup>

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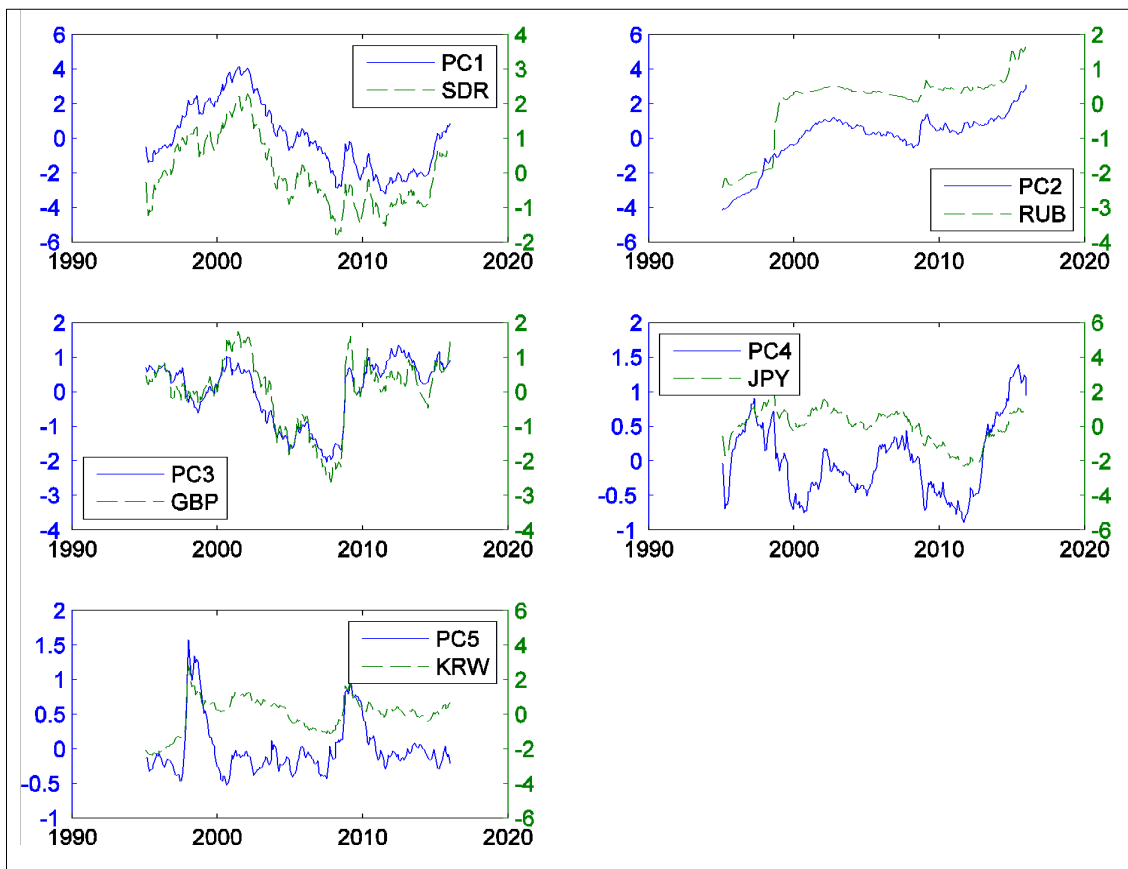
<sup>7</sup> Appendix 1 sets out charts of our fundamental variables.

<sup>8</sup> The data is produced from the research of Leo Krippner, and the details can be found on the website <http://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research>.

<sup>9</sup> We weight the currency pairs according to the foreign exchange turnover data of April 2016, which is from the Triennial Central Bank Survey conducted by the Bank for International Settlements (BIS). We thank Andrew Rose for this suggestion.

<sup>10</sup> In the following sections, we may use currency acronyms reported in this table for convenience.

**Figure 1: Principal Components of Currency Pairs**



Notes: This figure plots the first five principal components ( $I_t$ ) of our currency pairs, as well as their most correlated pairs. The log nominal exchange rates are standardized for better illustration.

Our results parallel and extend the findings in Engel, Mark, and West (2015) and Greenaway-McGrevy et al. (2015). Engel, Mark, and West (2015) construct global factors from a cross section of exchange rates and show that using factors combined with macro fundamentals can significantly improve forecasting performance. The identification of Greenaway-McGrevy et al. (2015) also motivates multilateral models for bilateral exchange rates. We confirm the previous findings and show that these global factors potentially correspond to financial market sophistication and regional effects; the former controls the efficiency of capital flows and the latter can be linked to trade. The economic appeal of these exchange rate factors is intuitive, as capital and trade flows are basic elements of the balance of international payments. In the following sections, we jointly model exchange rates with fundamentals related to commodity prices and reveal the time-varying dynamics of the system.

**Table 1: Correlation between Currencies and Principal Components**

<b>Africa</b>						
Central African Franc	0.94	0.13	0.25	0.00	-0.13	98.19%
S. African Rand	-0.01	0.92	0.15	0.20	-0.01	90.94%
Kenyan Shilling	-0.12	0.92	0.23	-0.02	-0.13	93.12%
Ghana Cedi	-0.39	0.90	0.07	0.10	-0.09	98.05%
Egyptian Pound	-0.52	0.78	-0.13	0.16	-0.14	93.65%
<b>America</b>						
Canadian Dollar	0.91	-0.25	0.06	0.06	0.02	90.16%
Peruvian New Sol	0.64	0.60	-0.39	-0.15	-0.08	94.28%
Chilean Peso	0.40	0.80	-0.16	-0.01	-0.12	84.34%
Colombian Peso	0.20	0.90	-0.30	-0.10	-0.11	95.89%
Brazilian Real	0.16	0.89	-0.20	0.02	-0.22	90.97%
Mexican Peso	-0.40	0.87	0.05	0.09	0.10	93.82%
Argentine Peso	-0.56	0.75	0.00	0.24	-0.10	93.98%
<b>Asia Pacific</b>						
Australian dollar	0.96	-0.04	-0.07	-0.04	0.06	92.41%
New Zealand dollar	0.93	-0.02	0.05	-0.24	0.12	92.98%
Singapore dollar	0.88	-0.01	-0.41	-0.20	0.05	97.51%
Japanese yen	0.72	-0.03	-0.38	0.56	0.07	98.68%
NT dollar	0.50	0.63	-0.44	-0.10	0.29	93.34%
Republic of Korean Won	0.39	0.64	0.10	-0.23	0.55	91.84%
Hong Kong dollar	0.27	0.45	-0.41	-0.37	-0.39	72.60%
Renminbi	0.70	-0.54	-0.38	-0.18	-0.09	96.45%
Thai baht	0.68	0.52	-0.37	-0.18	0.17	93.50%
Malaysian ringgit	0.53	0.68	-0.35	-0.06	0.25	93.01%
Philippines peso	0.18	0.84	-0.40	-0.23	0.04	95.56%
Indonesian rupiah	0.02	0.92	-0.16	-0.03	0.24	92.30%
Indian rupee	-0.12	0.90	0.26	0.25	0.01	94.52%
<b>Europe</b>						
Euro	0.94	0.13	0.25	0.00	-0.12	98.11%
Danish Krone	0.94	0.13	0.25	0.00	-0.12	97.98%
Czech Koruna	0.94	-0.24	0.13	0.02	-0.06	96.03%
Norwegian Krone	0.93	0.12	0.24	0.09	-0.01	93.41%
Swiss Franc	0.91	-0.28	-0.17	-0.15	-0.01	95.95%
Swedish Krona	0.91	0.23	0.20	-0.07	0.00	92.46%
Polish Zloty	0.78	0.47	0.19	-0.07	-0.05	86.08%
Hungarian Forint	0.53	0.75	0.26	0.04	-0.02	90.94%
British Pound	0.35	0.09	0.89	-0.07	0.08	93.09%
Iceland Krona	-0.32	0.64	0.63	0.02	0.16	94.10%
Russian Ruble	-0.05	0.95	-0.06	-0.09	-0.12	93.74%
Turkish Lira	-0.17	0.96	-0.13	-0.05	-0.06	97.80%
<b>Others</b>						
IMF SDR	0.97	0.02	0.19	0.13	-0.02	98.59%
Gold	0.84	-0.45	-0.24	-0.08	-0.01	97.61%

Notes: This table summarizes the correlation between each currency and five principal components ( $I_t$ ) extracted using the principal component method. The last column reports the adjusted  $R^2$  from the regression of each currency on the five principal components (PC1-5). This table reports 39 currencies (including the currency value of the SDR and the price of gold) and the US dollar is used as the base currency. The sample period is 1995:01-2015:12.

### 3.3 Variance Decomposition of Shocks to Fundamentals

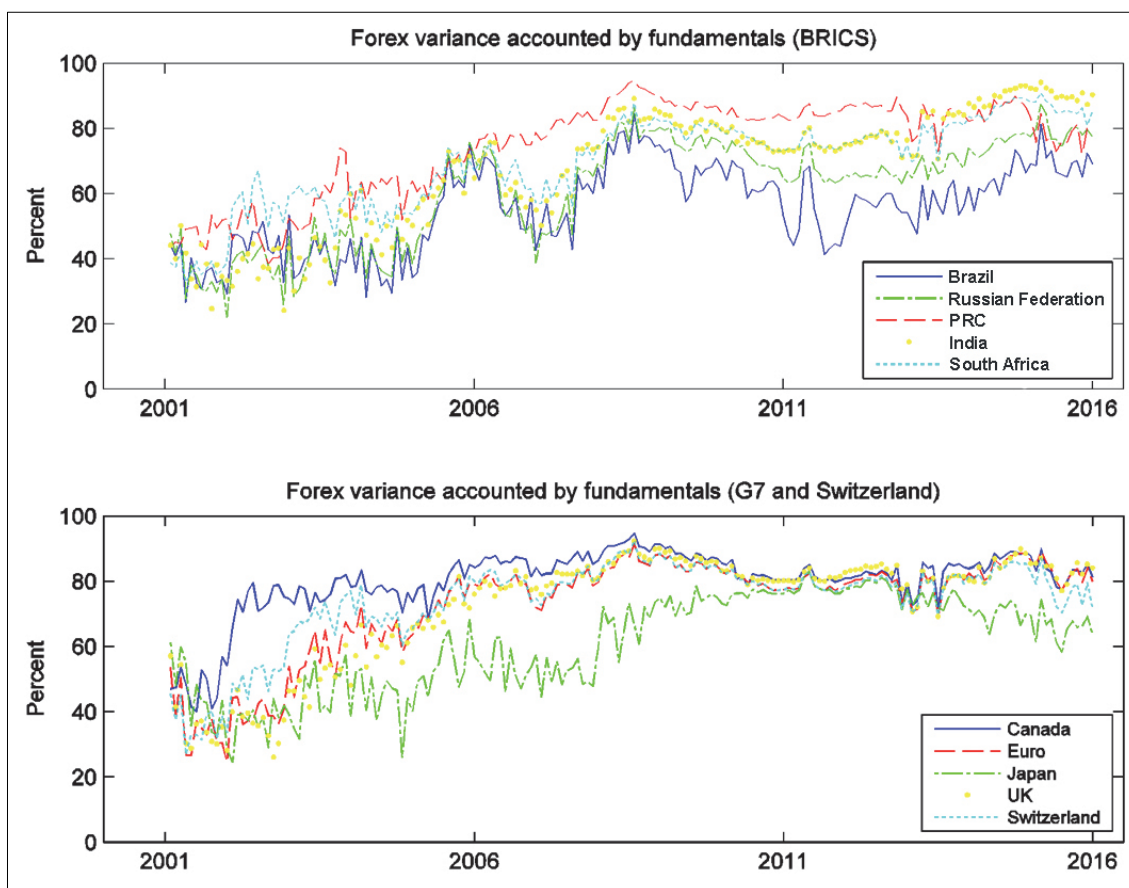
As discussed in the methodology section, our TVP-FAVAR jointly models the dynamics of two groups of variables  $f_t$  and  $I_t$ , and our identification scheme can directly evaluate the influence of  $f_t$  on exchange rates. In specific, there are six fundamentals: global oil prices, the PRC's industrial production, the PRC's import, US EFR, Euro-area SSR, and Japan SSR. The decomposition of these structural shocks is described in Equation (3).

Figure 2 shows the variance decomposition of our model, which displays time-varying patterns of exchange rate fluctuations across BRICS or G7 economies. The rest of the variance is accounted by the shocks to  $I_t$  in Equation (2). There are several sources that can induce the orthogonal shocks, which encompass non-market forces such as the exchange rate peg or capital controls, as well as various non-fundamental movements.<sup>11</sup> The patterns of different economies share a common trend. The importance of our fundamentals in driving exchange rate movements has significantly increased since 2005, despite a drop in 2007 for most of the economies. The Renminbi, however, has a stable upward trend after its 2005 exchange rate reform, but in 2015 there is a slight decline. We can interpret the increase in the share of fundamentals for the PRC as an effort to introduce a floating exchange rate regime, as it reflects the market expectations about the current economy. For almost all economies in the past 10 years, the fundamentals account for on average 70–80% of the exchange rate variance. A special case is the currency of Japan: For the Japanese Yen, the portion accounted by these fundamentals has been quite volatile in the past three years.

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<sup>11</sup> There are some possible explanations for the excess (non-fundamental) volatility: 1) Goldstein, Ozdenoren, and Yuan (2011) indicate that learning by the central bank from the market turns out to facilitate coordinated motives and thus large speculative attack, leading to non-fundamental volatility of exchange rates, regime transitions, and subsequently policy decisions. 2) Krugman (1979) assumes a government has limited reserves, and Morris and Shin (1998) further point out that currency attack by some speculators incentivize others to attack as well, forcing the government to abandon the current regime; both are able to produce the non-fundamental volatility observed in the data. 3) Jochum and Kodres (1998) show that currencies futures may have short-term impact on volatilities of exchange rates, and Sockin and Xiong (2015) suggest a feedback effect of commodity futures on commodities. 4) Menkhoff et al. (2012) show the existence of currency momentum, as agents are not always perfectly rational when pricing fundamentals into exchange rate. 5) Menkhoff et al. (2016) indicate the global imbalance risk factor (spread in economies external imbalances and their propensity to issue external liabilities in foreign currency) explains the cross-sectional variation in currency excess returns.

**Figure 2: Foreign Exchange Variance Accounted by Fundamentals**



PRC = People's Republic of China.

Notes: This figure plots for each economy the total fraction of 120-month-ahead forecast error variance of the foreign exchange (Forex) accounted by six fundamentals  $f_t$  we use in the TVP-FAVAR, i.e., the global oil price, the PRC's industrial production, the PRC's import, the US effective federal fund rate, and shadow short rates of the euro area and Japan. The upper chart displays the fractions of BRICS economies, and the lower chart displays the fractions of G7 economies and Switzerland. The decomposition is described in Equation (3).

Among all fundamentals, global oil prices and the PRC's IP are underlined in terms of their strong time variability in the variance decomposition. Tables 2 and 3 report the contribution of shocks to variance of exchange rates during different periods. It is clear that the global oil price is the dominant source before 2010, while the PRC's growth takes over the top position for almost all economies after 2010. Monetary policy shocks are comparatively small in the past five years. However, this does not mean policy rates are not important in driving exchange rates, as the variation in policy rates is potentially due to the reactions to changes in global oil prices or the PRC's growth, which account for more than 65% of the variance on average.<sup>12</sup>

<sup>12</sup> The generalized forecast error variance decomposition proposed by Koop, Pesaran, and Potter (1996) can validate this finding.

**Table 2: Contribution of Shocks to Variance of Exchange Rates  
(2001:01–2009:12)**

	Oil Price	The PRC IP	the PRC Import	US EFFR	Euro- area SSR	Japan SSR
Argentine Peso	0.43	0.09	0.13	0.10	0.01	0.05
Australian Dollar	0.36	0.08	0.07	0.08	0.02	0.06
Brazilian Real	0.30	0.05	0.07	0.03	0.05	0.04
Canadian Dollar	0.43	0.11	0.08	0.08	0.02	0.06
Swiss Franc	0.38	0.09	0.08	0.08	0.02	0.06
Chilean Peso	0.34	0.05	0.10	0.05	0.04	0.04
Renminbi	0.35	0.12	0.08	0.06	0.02	0.07
Colombian Peso	0.31	0.06	0.05	0.03	0.04	0.04
Czech Koruna	0.39	0.08	0.09	0.10	0.03	0.06
Danish Krone	0.37	0.07	0.07	0.09	0.01	0.07
Egyptian Pound	0.41	0.09	0.14	0.09	0.01	0.05
Euro	0.37	0.07	0.06	0.09	0.01	0.07
British Pound	0.36	0.08	0.06	0.08	0.02	0.06
Ghana Cedi	0.29	0.06	0.07	0.02	0.04	0.04
Hong Kong dollar	0.24	0.04	0.06	0.03	0.07	0.07
Hungarian Forint	0.36	0.08	0.08	0.07	0.02	0.06
Indonesian Rupiah	0.34	0.07	0.07	0.06	0.02	0.07
Indian Rupee	0.30	0.09	0.05	0.05	0.03	0.08
Iceland Krona	0.34	0.10	0.07	0.08	0.03	0.06
Japanese Yen	0.20	0.06	0.07	0.07	0.04	0.09
Kenyan Shilling	0.31	0.06	0.06	0.03	0.04	0.05
Republic of Korean Won	0.35	0.08	0.06	0.06	0.02	0.07
Mexican Peso	0.32	0.08	0.08	0.06	0.03	0.06
Malaysian Ringgit	0.34	0.07	0.08	0.06	0.02	0.07
Norwegian Krone	0.37	0.09	0.10	0.09	0.01	0.05
New Zealand Dollar	0.37	0.08	0.07	0.08	0.02	0.06
Peruvian New Sol	0.34	0.07	0.06	0.05	0.03	0.05
Philippines Peso	0.32	0.06	0.05	0.04	0.03	0.05
Polish Zloty	0.37	0.08	0.06	0.06	0.03	0.05
Russian Ruble (TOM)	0.31	0.06	0.06	0.03	0.04	0.05
Swedish Krona	0.36	0.08	0.06	0.08	0.02	0.06
Singapore Dollar	0.36	0.07	0.05	0.05	0.02	0.06
Thai Baht	0.34	0.07	0.06	0.06	0.02	0.07
Turkish Lira	0.30	0.06	0.05	0.03	0.04	0.05
NT dollar	0.33	0.08	0.06	0.06	0.02	0.07
Central African Franc	0.37	0.07	0.06	0.09	0.01	0.07
Gold	0.39	0.10	0.07	0.08	0.03	0.06
IMF SDR	0.36	0.08	0.07	0.10	0.02	0.08
S. African Rand	0.32	0.08	0.08	0.06	0.03	0.05

Notes: This table reports the fractions of the forecast error variance, at the 120-month horizon, explained by shocks to six fundamentals, respectively. For each economy, the fractions are averaged over the sample period 2001:01–2009:12.

**Table 3: Contribution of Shocks to Variance of Exchange Rates  
(2010:01–2015:12)**

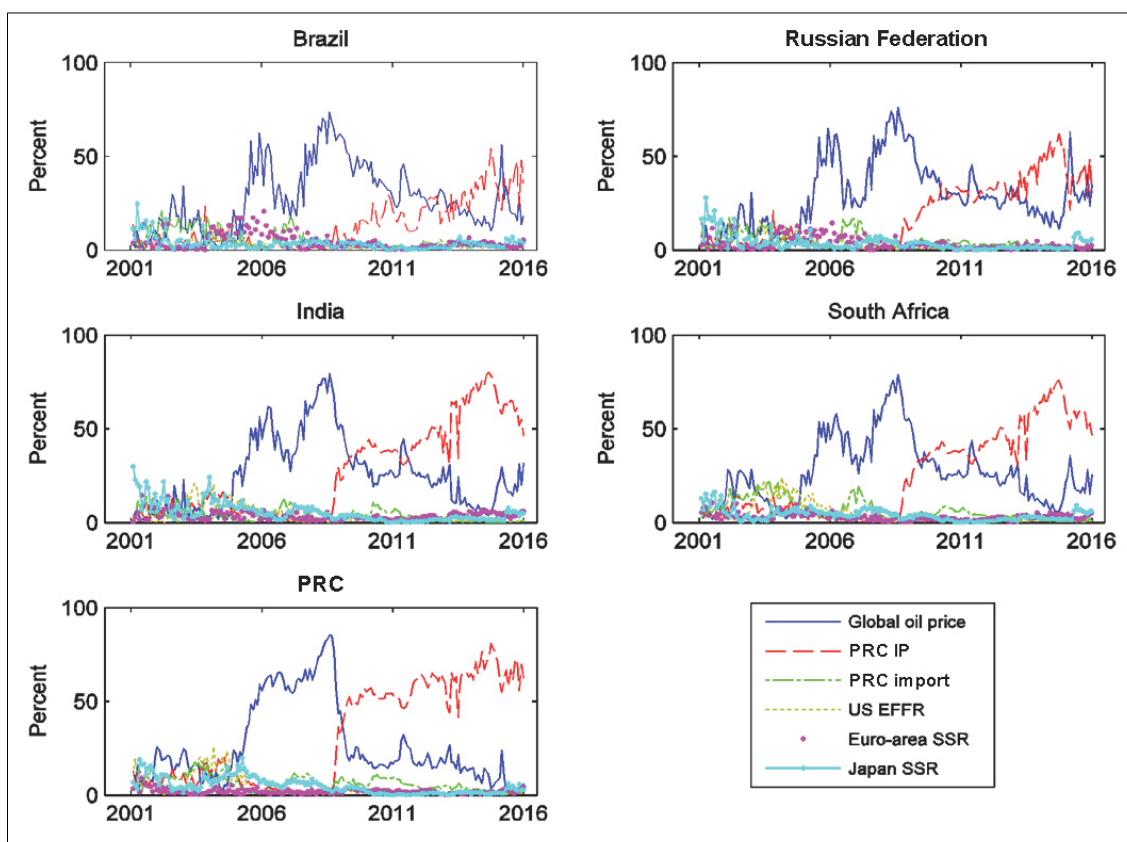
	Oil Price	The PRC IP	The PRC Import	US EFR	Euro-area SSR	Japan SSR
Argentine Peso	0.21	0.50	0.04	0.01	0.02	0.02
Australian Dollar	0.27	0.44	0.03	0.01	0.02	0.02
Brazilian Real	0.27	0.26	0.02	0.01	0.02	0.02
Canadian Dollar	0.28	0.46	0.04	0.01	0.03	0.02
Swiss Franc	0.26	0.44	0.04	0.01	0.02	0.02
Chilean Peso	0.35	0.26	0.03	0.01	0.02	0.02
Renminbi	0.15	0.62	0.04	0.01	0.01	0.01
Colombian Peso	0.33	0.27	0.03	0.01	0.01	0.02
Czech Koruna	0.24	0.47	0.04	0.01	0.03	0.02
Danish Krone	0.24	0.46	0.03	0.01	0.02	0.02
Egyptian Pound	0.20	0.52	0.04	0.01	0.02	0.02
Euro	0.24	0.46	0.03	0.01	0.02	0.02
British Pound	0.21	0.51	0.04	0.01	0.02	0.02
Ghana Cedi	0.17	0.47	0.05	0.01	0.01	0.01
Hong Kong dollar	0.25	0.18	0.07	0.01	0.05	0.02
Hungarian Forint	0.24	0.47	0.03	0.01	0.02	0.02
Indonesian Rupiah	0.25	0.46	0.02	0.01	0.02	0.02
Indian Rupee	0.21	0.52	0.02	0.01	0.03	0.02
Iceland Krona	0.19	0.56	0.04	0.01	0.02	0.01
Japanese Yen	0.22	0.34	0.06	0.01	0.05	0.04
Kenyan Shilling	0.25	0.42	0.03	0.01	0.02	0.01
Republic of Korean Won	0.24	0.48	0.03	0.01	0.02	0.01
Mexican Peso	0.24	0.46	0.03	0.01	0.02	0.01
Malaysian Ringgit	0.27	0.41	0.03	0.01	0.02	0.02
Norwegian Krone	0.26	0.46	0.03	0.01	0.03	0.02
New Zealand Dollar	0.25	0.46	0.03	0.01	0.02	0.02
Peruvian New Sol	0.30	0.36	0.03	0.01	0.02	0.02
Philippines Peso	0.29	0.33	0.02	0.01	0.02	0.02
Polish Zloty	0.27	0.44	0.03	0.01	0.03	0.02
Russian Ruble (TOM)	0.29	0.35	0.03	0.01	0.01	0.01
Swedish Krona	0.26	0.45	0.03	0.01	0.02	0.02
Singapore Dollar	0.30	0.37	0.03	0.01	0.02	0.02
Thai Baht	0.27	0.41	0.03	0.01	0.02	0.02
Turkish Lira	0.26	0.37	0.03	0.01	0.01	0.02
NT dollar	0.27	0.41	0.03	0.01	0.02	0.02
Central African Franc	0.24	0.46	0.03	0.01	0.02	0.02
Gold	0.24	0.46	0.04	0.01	0.03	0.02
IMF SDR	0.24	0.47	0.04	0.01	0.03	0.03
S. African Rand	0.22	0.49	0.03	0.01	0.02	0.02

Notes: This table reports the fractions of the forecast error variance, at the 120-month horizon, explained by shocks to six fundamentals, respectively. For each economy, the fractions are averaged over the sample period 2010:01–2015:12.



Figures 3 and 4 show the 120-month-ahead forecast error variance decomposition of six respective fundamentals over time. For the BRICS economies, the variance shares driven by global oil prices peak twice during the whole sample period (in 2006 and 2008, respectively). For the G7 currencies, there tends to be only one peak, which is in the global financial crisis.

**Figure 3: Time-varying Variance Decomposition (BRICS)**



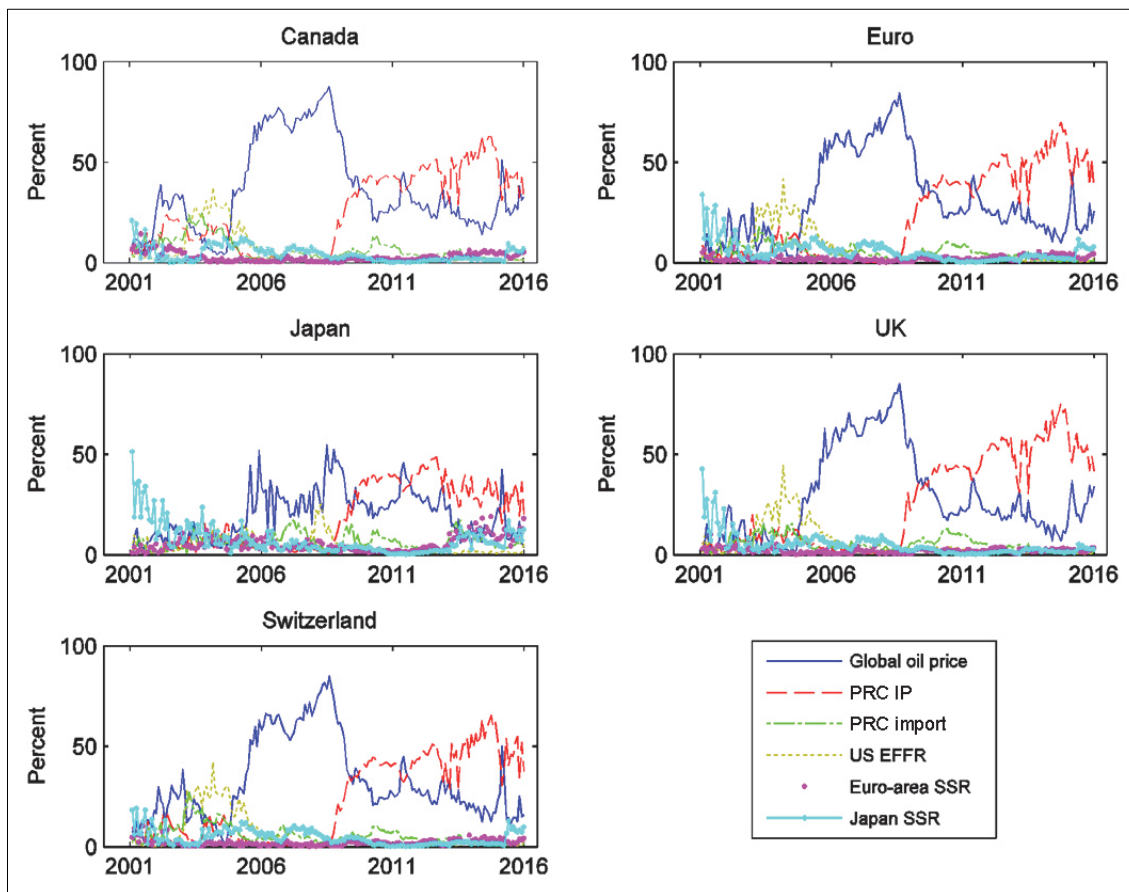
PRC = People's Republic of China.

Notes: This figure decomposes the 120-month-ahead forecast error variance of the foreign exchange accounted by fundamentals into six respective parts: the global oil price, the PRC's industrial production, the PRC's import, the US effective federal fund rate, and shadow short rates of the euro area and Japan. The economies reported are Brazil, the Russian Federation, India, the PRC, and South Africa (BRICS).

In 2008, global oil price shocks can account for a surprisingly high share (around 80%) of the variance of exchange rate movements; this finding holds for both commodity and non-commodity currencies, extending the results in Chen and Rogoff (2003). If investors infer the global demand for all industrial commodities from global oil prices, all currencies can be severely influenced by the oil price shocks.<sup>13</sup>

<sup>13</sup> A complement to the classical trade channel implied by the PPP theory is a channel about investor expectations, which means global (nominal) exchange rates can react quickly to nominal oil prices through the adjustment in market expectations about the global economic condition. This argument parallels the finding of Kilian (2009) that real oil prices are driven primarily by global commodity demand shocks from 2005 to 2008.

**Figure 4: Time-varying Variance Decomposition (G7 and Switzerland)**



PRC = People’s Republic of China.

Notes: This figure decomposes the 120-month-ahead forecast error variance of the foreign exchange accounted by fundamentals into six respective parts: the global oil price, the PRC’s industrial production, the PRC’s import, the US effective federal fund rate, and shadow short rates of the euro area and Japan. The regions reported are Canada, the euro area, Japan, Switzerland, and the UK.

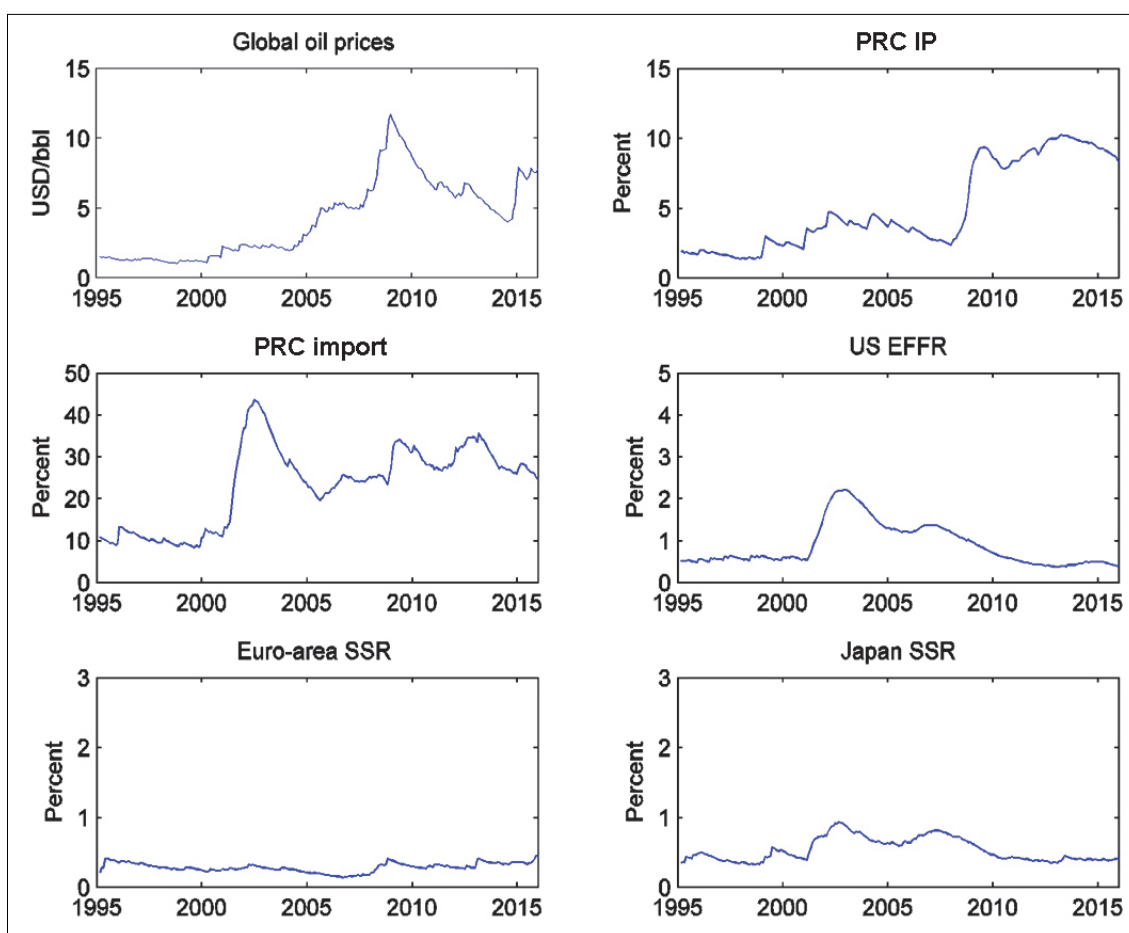
The relative importance of the PRC’s growth, measured by growth rates of industrial production, has increased significantly since 2008. The cutting point for most economies is around 2010, when the importance of the PRC’s growth exceeds global oil prices and becomes the most important driving force. In the last five years of our sample, the PRC’s growth accounts for 30–60% of the exchange rate variance across different currencies. Note that the influence is not necessarily through the trade channel, as the currencies of two major trading partners of the PRC, Brazil and Japan, do not have a strong and stable response to the growth shocks when compared with others.

The orthogonal shocks to the PRC’s import or the US monetary policy do not have strong impact on the exchange rate movements. That said, the monetary policy shocks are nonnegligible before 2006, primarily for advanced economies. The importance of the PRC’s import shocks peaks after the PRC joined WTO, accounting for 10–20% of the variance across economies.

### 3.4 An Interpretation of Impulse Responses

The economic rationale for the above results is by all means desirable. To interpret the results, in Figure 5 we firstly set out the time-varying uncertainty in the fundamentals estimated from our TVP-FAVAR model. We find that the volatility of global oil prices and the PRC's industrial production has risen significantly since the global financial crisis, while the monetary policy shocks to the US, the euro area, and Japan are relatively stable in our sample period. The impact of joining WTO on the PRC's import is very high, as the volatility has increased by four times since joining.

**Figure 5: Stochastic Volatility of Fundamentals**

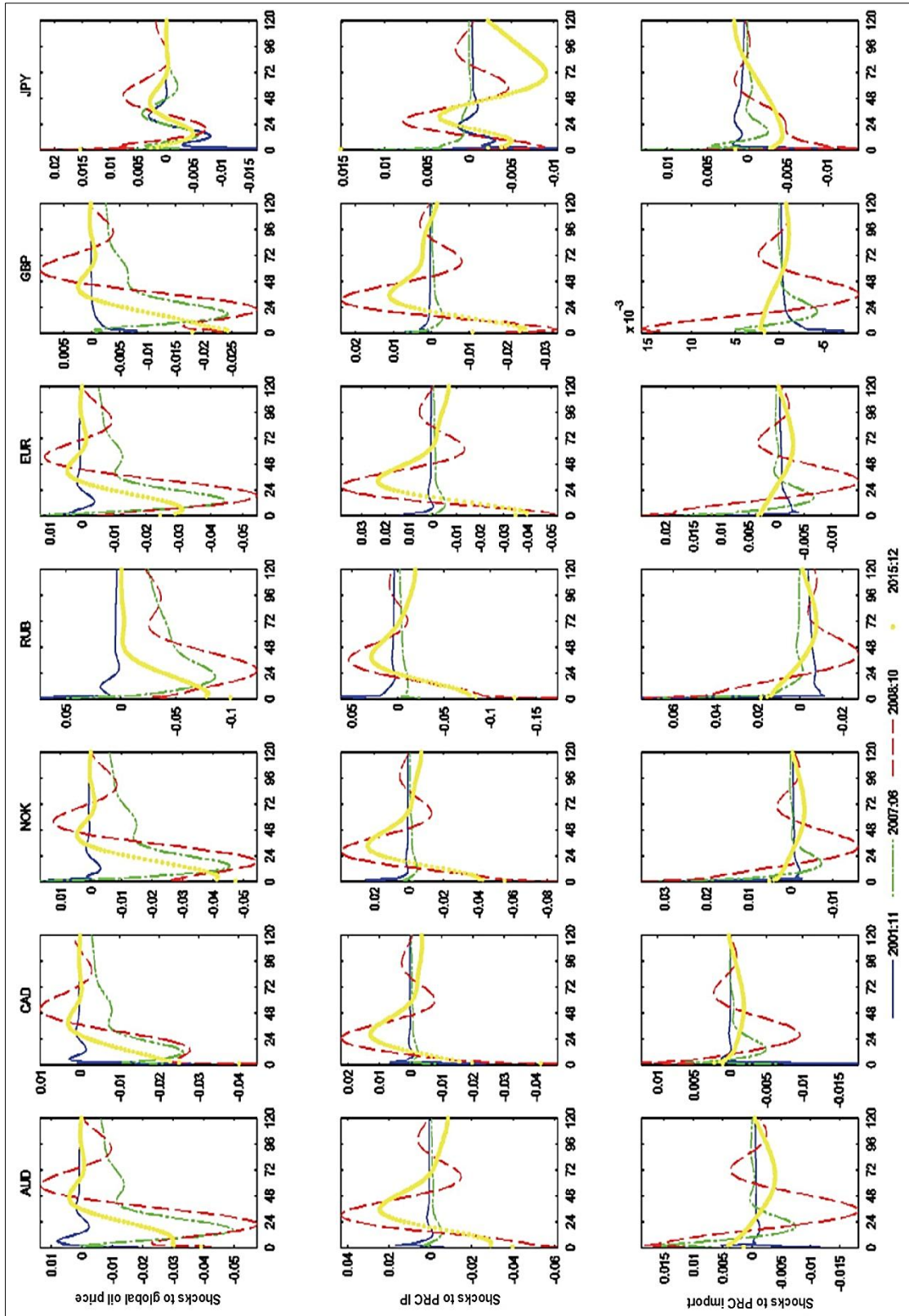


PRC = People's Republic of China.

Notes: This figure displays the (model-implied) time-varying standard deviations of the global oil price, the PRC's industrial production, the PRC's import, US EFR, Euro-area SSR, and Japan SSR.

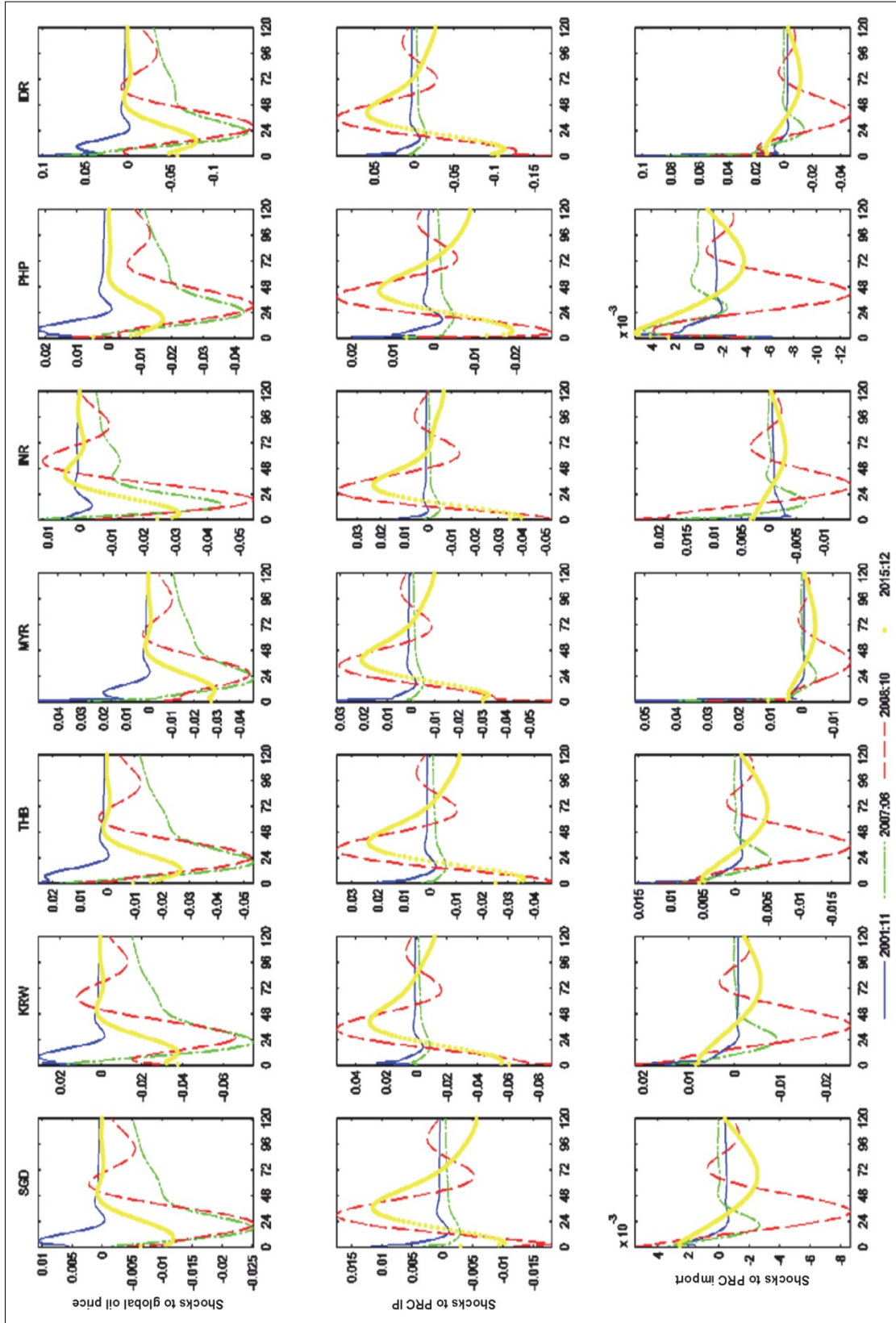
Figure 6 plot the impulse responses of log exchange rates to one standard deviation shocks (to fundamentals) for selected currencies, which helps understand how these shocks drive the exchange rate fluctuations. In the following we display the impact of oil prices, the PRC's industrial production and the PRC's import during four periods: 2001:11 (before the PRC joined the WTO), 2007:06 (after the PRC's 2005 exchange rate reform), 2008:10 (during the global financial crisis) and 2015:12 (the PRC's economic slowdown), and discuss the underlying economic mechanism.

Figure 6: Time-varying Impulse Response of Log Exchange Rates



Notes: This figure plots the impulse responses of the log exchange rates of different economies to one standard deviation shocks to respective fundamentals at different periods. The periods shown include: 2001:11 (before the PRC joined the WTO), 2007:06 (after the PRC's 2005 exchange rate reform), 2008:10 (during the financial crisis) and 2015:12 (the PRC's economic slowdown).

Figure 6 continued



Notes: This figure plots the impulse responses of the log exchange rates of different economies to one standard deviation shocks to respective fundamentals at different periods. The periods shown include: 2001:11 (before the PRC joined the WTO), 2007:06 (after the PRC's 2005 exchange rate reform), 2008:10 (during the financial crisis) and 2015:12 (the PRC's economic slowdown).

In the previous section, we find the global oil prices start to spark after 2005, which is again confirmed by Figure 6. The responses to oil price shocks are strong and quite stable across economies from 2007 to 2008, but are weak in 2001. The strong time variability is consistent with Chen, Rogoff, and Rossi (2010), who reveal strong evidence in favor of a time-varying relationship between exchange rates and commodity prices. During the 2007–2008 period, the exchange rates respond negatively to oil price shocks, peaking in the medium term (around 24 months). This mechanism can be explained by the standard purchasing power parity model, in which commodity price shocks can be considered as terms of trade fluctuations, through a channel similar to the Balassa-Samuelson effect (Balassa (1964) and Samuelson (1964)).<sup>14</sup> The exchange rate behavior at the end of our sample period (2015:12) changes substantially, except for the Japanese Yen. For most of the economies the exchange rate reacts swiftly to oil price shocks in 2015.<sup>15</sup>

Regarding the shocks to the PRC's growth, the impact on nominal exchange rates improves remarkably after the financial crisis. The impulse responses do not vary much across currencies. Moreover, the impulse responses of each currency are quite similar in terms of the magnitude and the pattern for 2008:10 and 2015:12, except that, for the latter period, the shocks are more persistent. There is a common pattern of overshooting in two years for all economies. These effects do not violate the PPP theory, but we suspect that the trade channel through which the PRC's growth affects the exchange rates only plays a limited role. On the one hand, when comparing the impulse responses in 2007:06 to that in 2008:10, it is difficult to explain why the impact on exchange rates increases so much in only one year. In particular, the importance of the PRC's growth increased rapidly before a sharp decrease in the PRC's import in 2008, which means the changes in exchange rates probably originated from the changes in investors' expectations. On the other hand, the influence of the PRC's growth is fast and stable for different currencies, even though the PRC may not be the major trade partner of all these economies. Moreover, the impact of the PRC's imports is small when compared with the PRC's growth, which is in sharp contrast to the argument that the trade channel is the major channel.

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<sup>14</sup> An increase in the world price of an economy's commodity exports will exert upward pressure on its real exchange rate, through its effect on wages and the demand for non-traded goods. In the presence of nominal price rigidities, the nominal exchange rate, rather than prices, will need to appreciate to restore the efficient relative price facing a positive price shock.

<sup>15</sup> This observation seems more consistent with the changes in investor expectations about the global commodity demand, which we have discussed in the last section.

The uncertainty in global oil prices and the PRC's growth has increased sharply since the financial crisis, which helps explain the magnitude of exchange rate fluctuations caused by these shocks. However, how are we to explain the rapid response of exchange rates to the latest shocks? Under the home bias assumption,<sup>16</sup> a demand shift biased toward the domestic good raises the price of the home good relative to that of the foreign (terms of trade), thereby appreciating the exchange rate, and vice versa. An alternative, but potentially more plausible explanation is to interpret these shocks as investors' demand shocks, which can influence the nominal exchange rates mainly by capital flows. As suggested by Pavlova and Rigobon (2007), an underlying source can produce cross-economy spillovers or comovement in currency markets, when considering substitution effects among currency pairs. In particular, by accounting for time-varying parameters, our model presents empirical evidence that the PRC's growth significantly affects nominal exchange rate movements across different economies in the past five years. The rapid response of exchange rates to this shock is more consistent with the movements in capital flows, for example, income effects or an investment channel. To the best of our knowledge, the finding is new to the literature.

## 4. ROBUSTNESS

### 4.1 A Simplified Model with Core Fundamentals

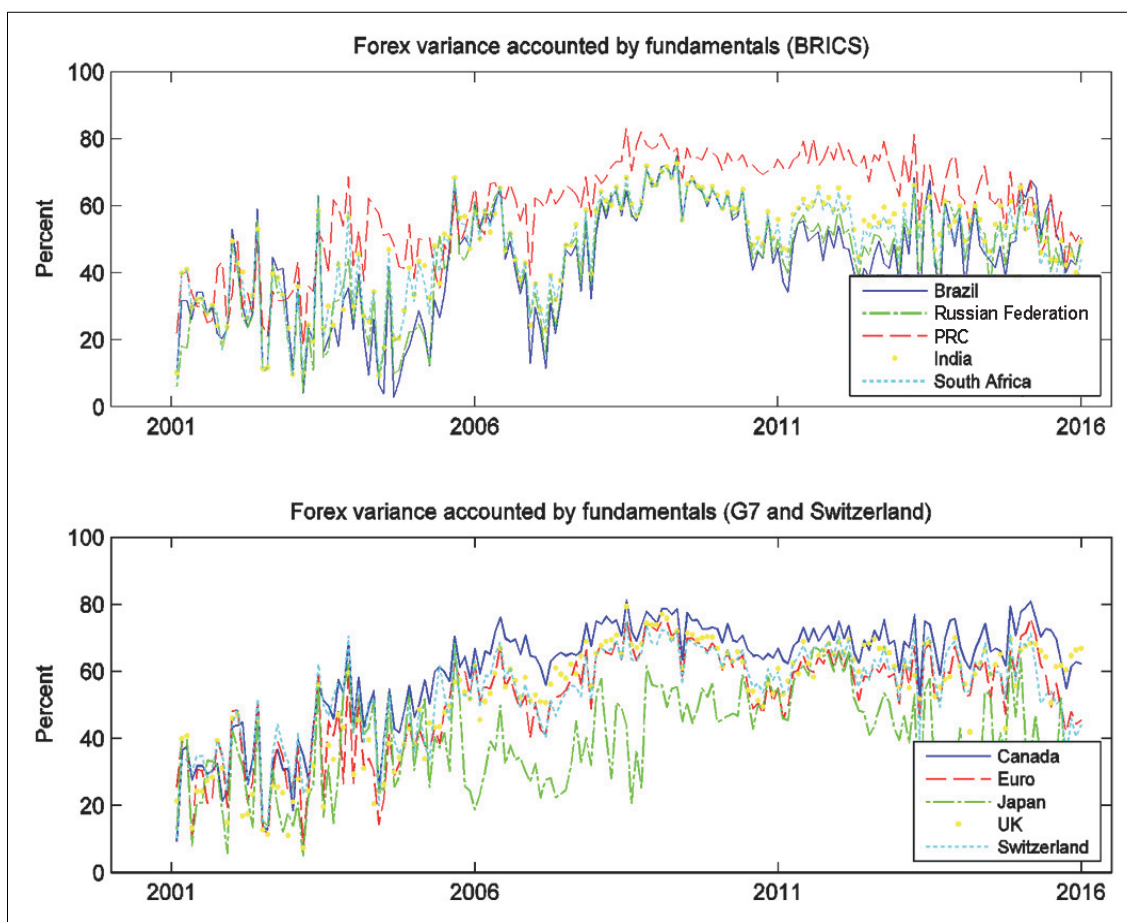
The previous sections have indicated that global oil prices and the PRC's growth are two core fundamentals that contribute to most of the variation in exchange rates. To verify this point, we consider a smaller TVP-FAVAR with only two core fundamentals and five common factors. Note that in the factor-augmented system, we always use five factors in order to account for most of the variance of log exchange rates. Moreover, as suggested by Bernanke, Boivin, and Eliasch (2005), using more factors is important for properly identifying the underlying transmission mechanism.

Using the smaller TVP-FAVAR, we have quantitatively similar results. As shown in Figure 7, two core fundamentals account for large fractions of the variance of different currencies. Therefore, we are convinced that the shocks to these two fundamentals are indeed dominant sources in driving global exchange rates.<sup>17</sup> In fact, with five latent factors we are able to recover the dynamic system insensitive to the choice of variables, as relevant information implied in exchange rates is incorporated. The FAVAR literature has indicated that the factor augmentation is useful in mitigating omitted variable bias or the non-fundamentalness problem; this argument also applies in this context.

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<sup>16</sup> The agent has preference bias toward the home good.

<sup>17</sup> More details about variance decomposition and impulse responses are available upon request.

**Figure 7: Foreign Exchange Variance Accounted by Two Core Fundamentals**

PRC = People's Republic of China.

Notes: This figure plots for each economy the total fraction of 120-month-ahead forecast error variance of the foreign exchange (Forex) accounted by two core fundamentals, i.e., the global oil price and the PRC's industrial production. The upper chart displays the fractions of BRICS economies, and the lower chart displays the fractions of G7 economies and Switzerland.

## 4.2 Generalized Forecast Error Variance Decomposition

One novel finding in this paper is that the PRC's growth is very important for exchange rate movements in the past five years. One may suspect that this conclusion is sensitive to the ordering of variables as we use Cholesky decomposition to identify structural shocks. To ensure the robustness, we need to consider an identification method that is not sensitive to the ordering of variables.

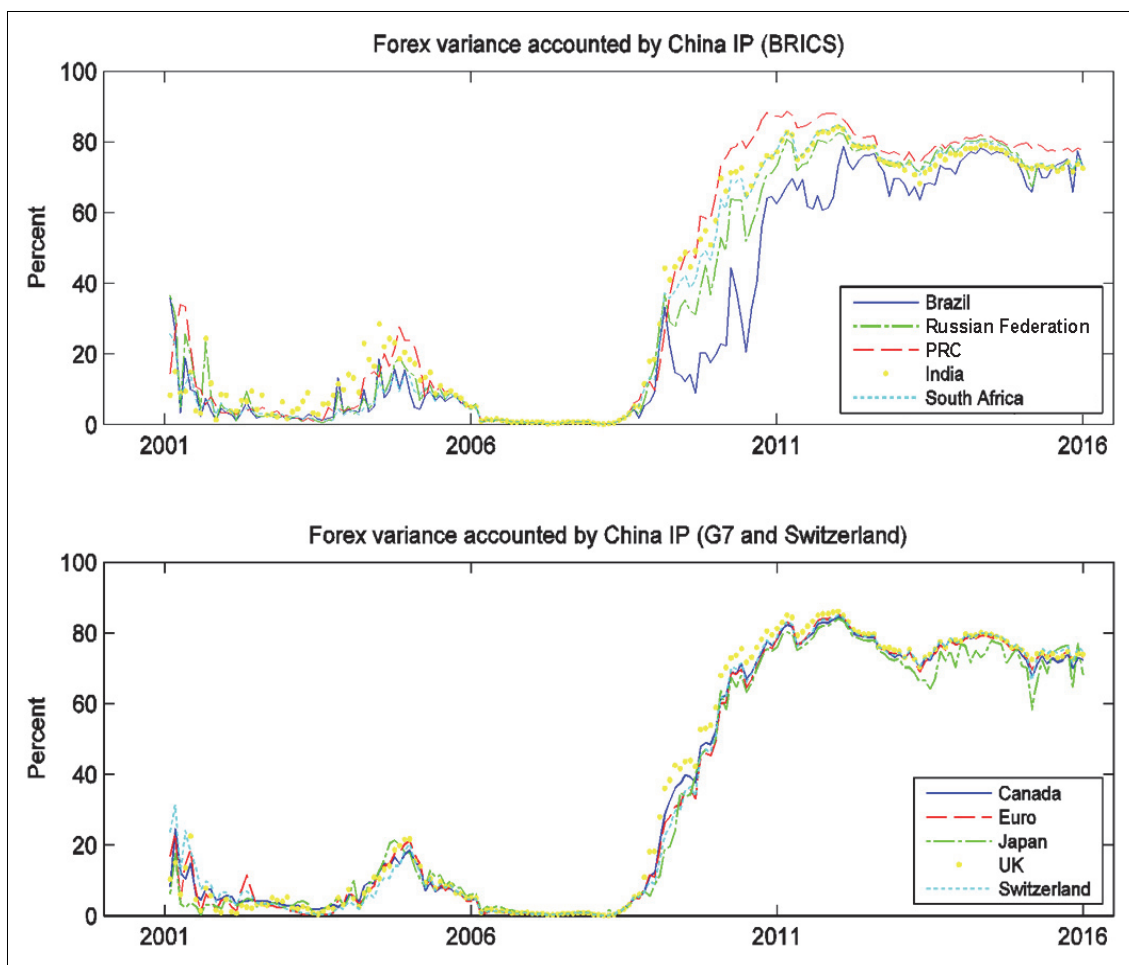
Proposed by Koop, Pesaran, and Potter (1996), the generalized variance decomposition is invariant to the ordering of the variables in the VAR.<sup>18</sup> The sums of forecast error variance contributions are not necessarily unity, so here we calculate the normalized weights, which add up to unity following Diebold and Yilmaz (2014). Figure 8 shows the results from the generalized variance decomposition. This decomposition scheme actually strengthens the previous results, suggesting that a different ordering in the Cholesky decomposition is highly unlikely to alter our new

<sup>18</sup> We encourage readers to consult the original papers for motivation and background.



finding. The contribution of the PRC’s growth is very distinctive, especially in the past five years. At each time point, the fractions are even more consistent across economies.

**Figure 8: Foreign Exchange Variance Accounted by the People’s Republic of China’s Growth**



PRC = People’s Republic of China.

Notes: This figure plots for each economy the fraction of 120-month-ahead generalized forecast error variance of the foreign exchange (Forex) accounted by the PRC’s industrial production. The upper chart displays the fractions of BRICS economies, and the lower chart displays the fractions of G7 economies and Switzerland.

### 4.3 Parameter Uncertainty

In this paper we conduct a Bayesian analysis, allowing for parameter uncertainty. In specific, the coefficients of the VAR system are uncertain and follow a normal distribution. Therefore, we need to consider whether the contribution of the PRC’s growth is robust to the uncertainty in the parameters.

We conduct the following robustness check. At each point in time, we generate 1,000 draws from the estimated distribution. For each draw, we use the generalized variance decomposition to decompose the shock to the PRC’s growth. By doing so, we can easily calculate the median and the 90% credible interval for the average of the fraction explained by the PRC’s growth shock over a sample period. Table 4 shows the contribution of the shock to the PRC’s growth is highly consistent for all economies in

each of the sample periods we consider. The 90% credible intervals are reasonably tight. Based on this evidence, our new finding is very robust: The contribution of the PRC's growth shock to global exchange rates is statistically significant.

**Table 4: Contribution of the People's Republic of China's Growth Shock to Variance of Exchange Rates**

	Median	90% Credible Interval	Median	90% Credible Interval
Argentine Peso	0.187	[0.158,0.219]	0.721	[0.675,0.761]
Australian Dollar	0.187	[0.157,0.217]	0.721	[0.676,0.762]
Brazilian Real	0.187	[0.157,0.217]	0.718	[0.675,0.758]
Canadian Dollar	0.187	[0.158,0.217]	0.721	[0.675,0.763]
Swiss Franc	0.187	[0.157,0.217]	0.720	[0.676,0.762]
Chilean Peso	0.188	[0.157,0.217]	0.718	[0.674,0.760]
Renminbi	0.187	[0.159,0.217]	0.721	[0.676,0.763]
Colombian Peso	0.188	[0.157,0.217]	0.718	[0.673,0.759]
Czech Koruna	0.186	[0.158,0.217]	0.722	[0.676,0.763]
Danish Krone	0.187	[0.157,0.216]	0.721	[0.678,0.761]
Egyptian Pound	0.187	[0.159,0.217]	0.721	[0.676,0.761]
Euro	0.187	[0.157,0.216]	0.721	[0.679,0.761]
British Pound	0.187	[0.159,0.219]	0.722	[0.678,0.761]
Ghana Cedi	0.188	[0.158,0.217]	0.719	[0.673,0.760]
Hong Kong dollar	0.188	[0.157,0.216]	0.718	[0.674,0.759]
Hungarian Forint	0.187	[0.157,0.216]	0.722	[0.677,0.762]
Indonesian Rupiah	0.187	[0.157,0.218]	0.722	[0.677,0.759]
Indian Rupee	0.188	[0.159,0.217]	0.722	[0.677,0.762]
Iceland Krona	0.187	[0.159,0.219]	0.723	[0.680,0.761]
Japanese Yen	0.187	[0.159,0.218]	0.719	[0.676,0.758]
Kenyan Shilling	0.187	[0.158,0.217]	0.720	[0.673,0.761]
Republic of Korean Won	0.187	[0.159,0.218]	0.722	[0.675,0.761]
Mexican Peso	0.187	[0.159,0.216]	0.720	[0.675,0.761]
Malaysian Ringgit	0.187	[0.158,0.217]	0.721	[0.676,0.760]
Norwegian Krone	0.187	[0.157,0.216]	0.722	[0.676,0.764]
New Zealand Dollar	0.187	[0.158,0.216]	0.722	[0.677,0.762]
Peruvian New Sol	0.187	[0.156,0.217]	0.720	[0.674,0.759]
Philippines Peso	0.187	[0.158,0.217]	0.718	[0.675,0.759]
Polish Zloty	0.187	[0.157,0.216]	0.721	[0.676,0.760]
Russian Ruble (TOM)	0.187	[0.157,0.217]	0.718	[0.675,0.760]
Swedish Krona	0.187	[0.157,0.216]	0.722	[0.677,0.762]
Singapore Dollar	0.187	[0.159,0.217]	0.720	[0.676,0.761]
Thai Baht	0.187	[0.159,0.217]	0.721	[0.677,0.760]
Turkish Lira	0.188	[0.157,0.217]	0.719	[0.674,0.760]
NT dollar	0.187	[0.158,0.216]	0.721	[0.673,0.759]
Central African Franc	0.187	[0.158,0.216]	0.721	[0.678,0.761]
Gold	0.187	[0.158,0.217]	0.721	[0.674,0.761]
IMF SDR	0.187	[0.158,0.216]	0.722	[0.677,0.762]

S. African Rand	0.188	[0.159,0.216]	0.721	[0.676,0.761]
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Notes: This table reports the fraction of the forecast error variance, at the 120-month horizon, explained by the PRC's growth shock. The fractions are calculated based on the generalized variance decomposition method. For each economy, the fractions are averaged over the specific sample period.

## 5. CONCLUSION

This paper explores the movements in US dollar-based nominal exchange rates across 39 regions and potential sources that drive the comovement. Building upon a factor structure, we identify five exchange rate common factors that capture 95% of the variance of global exchange rates. We further analyze the evolution of exchange rate dynamics using a TVP-FAVAR model, which shows that our fundamentals have become the main driver of exchange rate movements in the past 10 years. Our results reveal that uncertainty in global oil prices and the PRC's growth has increased substantially since the global financial crisis. Moreover, the increased uncertainty is of essence in understanding why global exchange rate fluctuations can be largely explained by fundamentals. We find that global oil prices are extremely important during the global financial crisis, while the PRC's growth dominates during the past five years. In addition to the trade channel implied by the PPP theory, we link unexpected changes in the PRC's growth to shocks to global investors' demand for exchange rate assets. In this paper we underline the impact of the PRC on US exchange rates, but this does not mean other factors, for example, US industrial production or stock market volatility, is unimportant. A more comprehensive analysis can be done by considering a richer set of variables, and we leave this direction for further research.

The policy implication of this paper is clear and straightforward: News about oil prices or the PRC's growth will probably affect US dollar exchange rates and, therefore, the economic conditions of connected economies or regions through a currency channel. For example, a potential "trade war" between the US and the PRC can cause a sharp increase in exchange rate variance, as investors believe this news is closely related to the PRC's growth and commodity prices. The transmission is speedy, so when faced with undesirable news, a prompt reaction of policy makers is recommended in order to offset the exchange rate fluctuations.

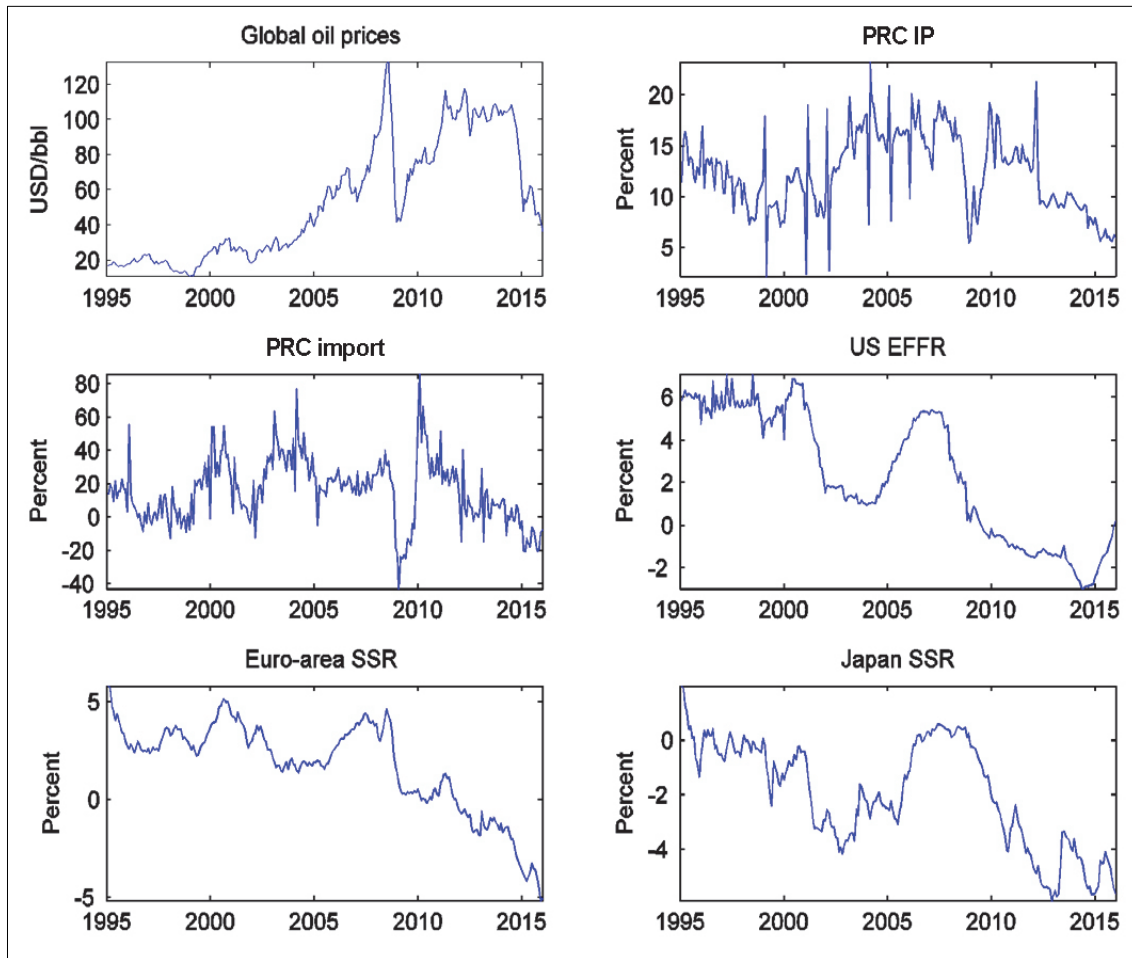
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## APPENDIX 1: DATA APPENDIX

Figure A1: Charts of Fundamentals



PRC = People's Republic of China.

Notes: This figure displays the fundamental variables: global oil price, the PRC's industrial production, the PRC's import, US EFR, Euro-area SSR, and Japan SSR.

## APPENDIX 2: ECONOMETRIC METHOD

We conduct the Kalman filter estimation for the state space model with the below equations:

$$Z_t = X_t \beta_t + v_t,$$

$$\beta_{t+1} = \beta_t + \mu_t,$$

where  $Z_t$  is an  $n \times 1$  vector of variables,  $X_t = I_n \otimes [Z'_{t-1}, \dots, Z'_{t-p}]'$ ,  $\beta_t$  are VAR coefficients,  $v_t \sim N(0, \Sigma_t)$  with  $\Sigma_t$  an  $n \times n$  covariance matrix, and  $\mu_t \sim N(0, Q_t)$ .

Given that all the data from time 1 to  $t$  denoted as  $D_t$ , the Bayesian solution to updating about the coefficients  $\beta_t$  takes the form

$$\begin{aligned} p(\beta_t | D_t) &\propto \mathbf{L}(\beta_t; Z_t) p(\beta_t | D_{t-1}), \\ p(\beta_t | D_{t-1}) &= \int_{\wp} p(\beta_t | D_{t-1}, \beta_{t-1}) p(\beta_{t-1} | D_{t-1}) d\beta_{t-1}, \end{aligned}$$

where  $\wp$  is the support of  $\beta_{t-1}$ . The solution to this problem can be defined using a Bayesian generalization of the typical Kalman filter recursions. Given an initial condition  $\beta_0 \sim N(m_0, \Phi_0)$  we can define (cf. West and Harrison (1997)):<sup>1</sup>

1. Posterior at time  $t - 1$

$$\beta_{t-1} | D_{t-1} \sim N(m_{t-1}, \Phi_{t-1}),$$

2. Prior at time  $t$

$$\beta_t | D_{t-1} \sim N(m_{t|t-1}, \Phi_{t|t-1}),$$

3. where  $m_{t|t-1} = m_{t-1}$  and  $\Phi_{t|t-1} = \Phi_{t-1} + Q_t$ .

4. Posterior at time  $t$

$$\beta_t | D_t \sim N(m_t, \Phi_t),$$

5. where  $m_t = m_{t|t-1} + \Phi_{t|t-1} X'_t (V_t^{-1})' \tilde{v}_t$  and  $\Phi_t = \Phi_{t|t-1} - \Phi_{t|t-1} X'_t (V_t^{-1})' X_t \Phi'_{t|t-1}$ , with  $\tilde{v}_t = Z_t - X_t m_{t|t-1}$  the prediction error and  $V_t = X_t \Phi_{t|t-1} X'_t + \Sigma_t$  its covariance matrix.

Following the discussion above, we need to find estimates for  $\Sigma_t$  and  $Q_t$  in the formulas above. We define the time  $t$  prior for  $\Sigma_t$  to be

$$\Sigma_t | D_{t-1} \sim iW(S_{t-1}, \delta n_{t-1}),$$

while the posterior takes the form

$$\Sigma_t | D_t \sim iW(S_t, n_t),$$

---

<sup>1</sup> For a parameter  $\theta$  we use the notation  $\theta_{t|s}$  to denote the value of parameter  $\theta_t$  given data up to time  $s$  (i.e.  $D_s$ ) for  $s > t$  or  $s < t$ . For the special case where  $s = t$ , I use the notation  $\theta_{t|t} = \theta_t$ .

where  $n_t = \delta n_{t-1} + 1$  and  $S_t = \delta S_{t-1} + n_t^{-1} (S_{t-1}^{0.5} V_{t-1}^{-0.5} \tilde{v}_{t|t-1} \tilde{v}'_{t|t-1} V_{t-1}^{-0.5} S_{t-1}^{0.5})$ . In this formulation,  $v_t$  is replaced with the one-step ahead prediction error  $\tilde{v}_{t|t-1} = Z_t - m_{t|t-1} X_t$ . The estimate for  $\Sigma_t$  is approximately equivalent numerically to the Exponentially Weighted Moving Average (EWMA) filter  $\hat{\Sigma}_t = \delta \hat{\Sigma}_{t-1} + (1 - \delta) v_t v_t'$ . The parameter  $\delta$  is the decay factor, where for  $0 < \delta < 1$ . In fact, Koop and Korobilis (2013) apply such a scheme directly to the covariance matrix  $\Sigma_t$ , which results in a point estimate. In this case, by applying variance discounting methods to the scale matrix  $S_t$ , we are able to approximate the full posterior distribution of  $\Sigma_t$ .

Regarding  $Q_t$ , we use the forgetting factor approach in Koop and Korobilis (2013); see also West and Harrison (1997) for a similar discounting approach. In this case  $Q_t$  is set to be proportionate to the filtered covariance  $\Phi_{t-1} = cov(\beta_{t-1} | D_{t-1})$  and takes the following form

$$Q_t = (\Lambda^{-1} - 1) \Phi_{t-1},$$

for a given forgetting factor  $\Lambda$ .

The brief interpretation of forgetting factors is that they control how much “recent past” information will be used. With the exponential decay for the forgetting factors, if it takes a value of 0.99, the information 24 periods ago (two years for monthly data) receives around 80% as much weight as the information of last period. If the forgetting factor takes 0.95, then forecast performance 24 periods ago receives only about 30% as much weight. The similar implication holds for the decay factor. Following Koop and Korobilis (2013),  $\delta$  and  $\Lambda$  are calibrated to values close to 1 to ensure stability, which are 0.94 and 0.99, respectively.  $\delta$  is set to a smaller value while ensuring the stability of the system, as it can provide a higher cumulative sum of predictive log-likelihood.



## APPENDIX 3: STRUCTURAL INTERPRETATION ABOUT THE FACTOR STRUCTURE

Following and extending Engel and West (2005) and Chen, Rogoff, and Rossi (2010), the present-value model for the log nominal exchange rate  $s_{t,i}$  of economy  $i$  at time  $t$  is given in the following form:

$$s_{t,i} = \gamma_i^G \sum_{j=0}^{\infty} \psi_i^j E_t(z_{t+j}^G | I_t) + \gamma_i \sum_{j=0}^{\infty} \phi_i^j E_t(z_{t+j,i} | I_{t,i}),$$

where  $\gamma$ ,  $\psi$  and  $\phi$  are parameters dictated by the specific structural model,  $E_t$  is the expectation operator given a specific information set  $I_t$  or  $I_{t,i}$ , and  $z_t^G$  and  $z_{t,i}$  collect global and economy-specific fundamentals, respectively. This model implies the cross section of exchange rates contains the information of global fundamentals, although we have not specified what would be the fundamentals at this stage.

Following Engel and West (2006), a structural present-value model can be simplified, if we assume the underlying dynamics about the fundamentals are described by VAR forecasting equations. In particular, we can show the above present-value model is equivalent to a reduced-form representation in which log nominal exchange rates are linear in the global information set (factors). In this paper, our focus is not on the structural parameters and hence they will not be identified in our analysis.

## APPENDIX 4: ADDITIONAL RESULTS

### 4.1 Comparison with the Random Walk Model

Our focus in this paper is to economically explain the movements of US dollar exchange rates, which cannot be done using a random walk model. That said, it is informative to compare the TVP-FAVAR to the random walk model, in order to evaluate how well our approach models and forecasts exchange rates. Figure A4.1 shows the TVP-FAVAR and the random walk track the observed exchange rates well, but the TVP-FAVAR tends to predict higher variance of exchange rate innovations.<sup>1</sup> The random walk model, despite its lack of economic content, has better fits because of the high persistence of exchange rates. This observation is consistent with the empirical evidence in the previous literature that it is difficult to outperform the random walk, at least in the context of point forecasts. However, interest centers on more than just point forecasts when it comes to managing exchange rate risk, as suggested in Sarno and Valente (2005) and Rossi (2013). Economic agents may have loss functions that do not depend only on the realizations of future values of variables but also on the risk of these variables. In this case, agents are interested in forecasting not only the mean but also the variance, and the full predictive densities matter more than only point forecasts. Therefore, we go beyond point forecasts by evaluating the whole predictive density of a model specification.

The evaluation of one-month ahead density forecasts is shown in Figure A4.2. At each point in time, we use the conditional estimates of the TVP-FAVAR parameters assuming the future values are constant (unbiased forecasts), and the predictive likelihood function can be constructed using the estimated parameters.<sup>2</sup> In terms of the cumulative sum of predictive log-likelihood, the TVP-FAVAR outperforms the random walk benchmark for two thirds of the currency pairs, and is similar to the random walk for the rest of the pairs (except for XAU). The TVP-FAVAR has stable forecast performance and positive cumulative sums in general. This suggests economic agents using the TVP-FAVAR are potentially better off in the risk-return tradeoff, as they correctly perceive the level of variation in exchange rates and are not likely to have extreme portfolio positions.<sup>3</sup>

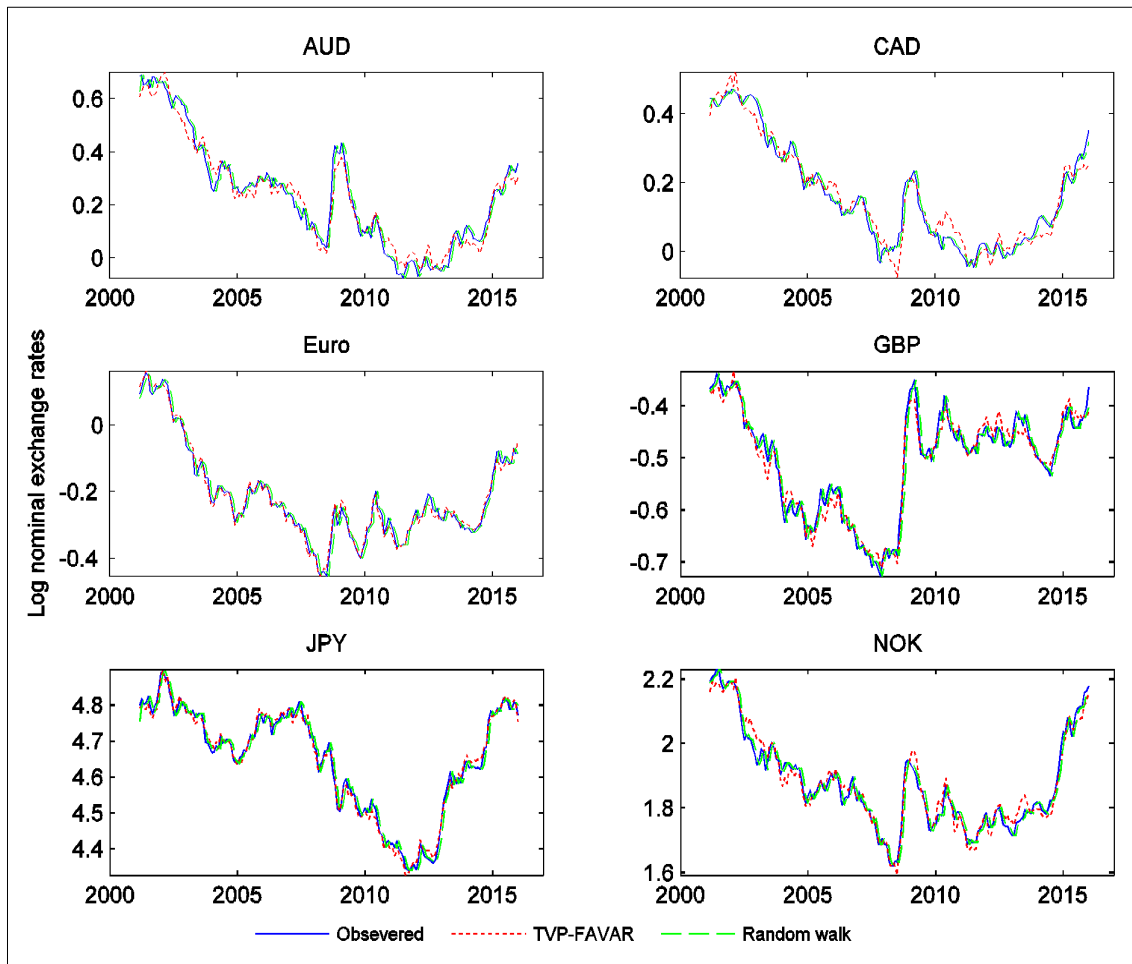
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<sup>1</sup> We set out six currency pairs for the sake of brevity, but the results are similar for other currencies.

<sup>2</sup> Our implementation here is not a truly out-of-sample exercise because the cross-sectional parameters  $a_i^*$  are estimated using the full sample to avoid small-sample bias. But time-series parameters in the TVP-FAVAR system are conditional estimates.

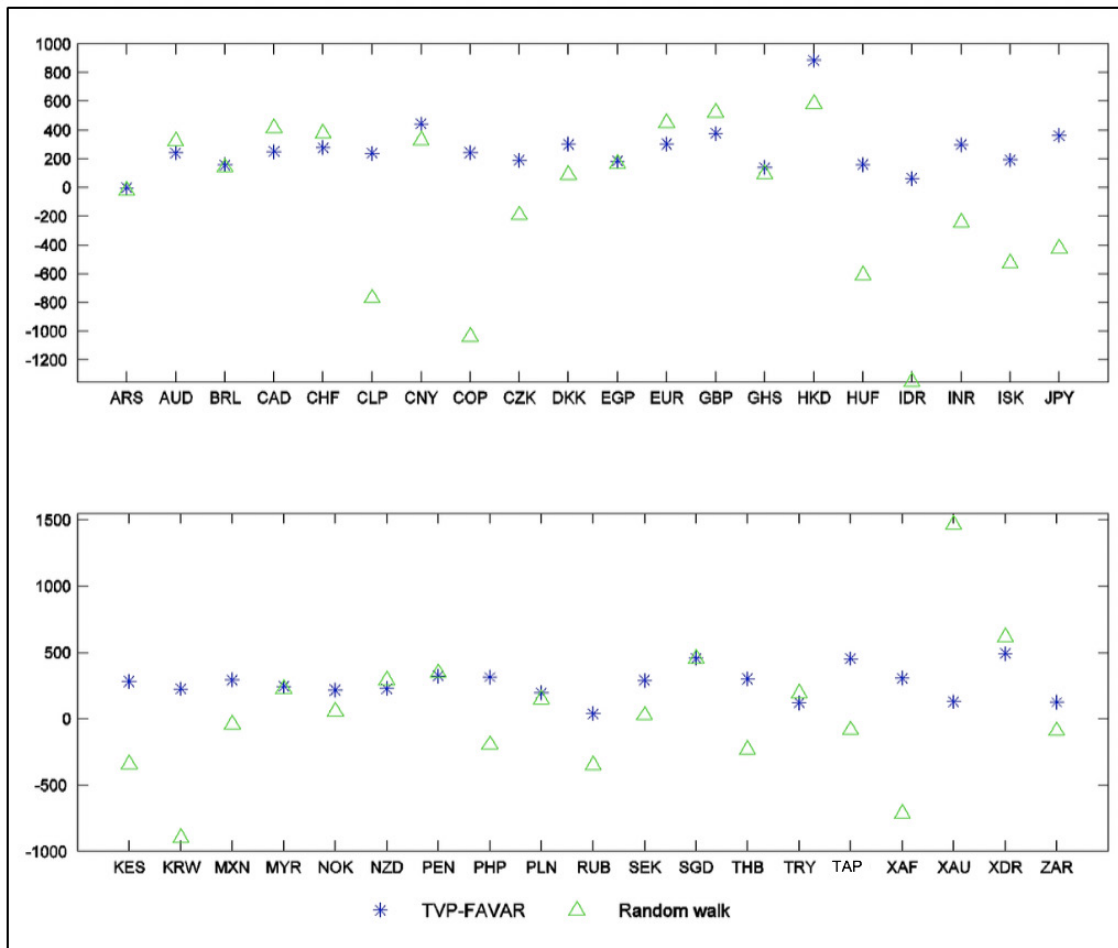
<sup>3</sup> See Sarno and Valente (2005) for details about the economic utility evaluation.

**Figure A4.1: TVP-FAVAR vs. Random Walk**



Notes: This figure compares the fits of the TVP-FAVAR and the random walk model for six US dollar exchange rates. The estimates of the random walk model are one-month lagged values of the observed nominal exchange rates.

**Figure A4.2: Cumulative Sum of Predictive Log-likelihood**



Notes: This figure compares the one-month ahead density forecasts of the TVP-FAVAR and the random walk model for 39 US dollar exchange rates. The cumulative sum of predictive log-likelihood is calculated based on conditional forecasts, and the forecasting period is from 2000:12 to 2015:12. The conditional variance of the TVP-FAVAR is model-implied, and the conditional variance of the random walk is estimated recursively using exchange rate observations up to and including the time when forecasts are made.