Green Finance

Green Finance, 1(4): 346–363.
DOI: 10.3934/GF.2019.4.346
Received: 13 November 2019
Accepted: 20 November 2019
Published: 22 November 2019

http://www.aimspress.com/journal/GF

Research article

Sustainable exchange rates in China: Is there the heterogeneous effect of economic policy uncertainty?

Liming Chen[1], Ziqing Du[1,*] and Yong Tan[2]

[1] College of Finance and Statistics, Hunan University, Changsha, 410006, P.R. China
[2] Department of Accountancy, Finance and Economics, Huddersfield Business School, University of Huddersfield, Queensgate, HD1 3DH, U.K.

*** Correspondence:** Email: scarlett107@hnu.edu.cn; Tel: +8616674201007.

Abstract: This study is to investigate the heterogeneous effect of economic policy uncertainty (EPU) on the exchange rate volatility of China using quantile regression for the period Jan 2003–Jan 2019. This paper significantly contributes to the empirical literature by taking into account the effect in individual and distributional heterogeneity and exploring the transmission mechanism of heterogeneity. The results demonstrate that, first, EPU from different countries have a heterogeneous impact on China's exchange rate volatility both direction as well as distribution. Second, this paper further assesses the EPU transmission mechanism of bilateral trading and interest rate difference is mixed. These results provide policymakers with critical policy recommendations that contribute to the reduction of the exchange rate volatility and ensure stable economic development in China.

Keywords: exchange rate volatility; economic policy uncertainty; heterogeneity; quantile regression

JEL Codes: C32, C51, F31

1. Introduction

Economic policy uncertainty (EPU) as an important factor in the exchange rate volatility, has long been neglected in the literature. There is a growing literature that investigates the link between EPU and economics activities. One stream of the literature focuses on that EPU has an influence on a number of economic fundamentals, such as inflation, unemployment, economic development, financial stress (Aastveit et al., 2017; Brogaard and Detzel, 2015; Caggiano et al., 2017; Jones and Olson, 2013; Scheffel, 2015; Sun et al., 2017). Another stream of literature dealing with the relationship between EPU and asset price investigates the effect of EPU on the mortgage rate, gold futures, housing returns, commodity markets, stock and bond markets (Arouri et al., 2016; Bahmani-Oskooee and Saha, 2019; Christou et al., 2017; Cebula and Boylan, 2019; Fang et al., 2018; Ko and Lee, 2015; Li et al., 2015; Li and Peng, 2017; Liu and Zhang, 2015; Phan et al., 2018; Shahzad et al., 2017; Tsai, 2017; Wang et al., 2015).

Theoretical determinants of the exchange rate volatility have taken domestic and international perspectives. In terms of domestic, empirical evidence suggests that changes in the exchange rate volatility depend upon two perspectives such as policy regulations and market interaction. On one hand, Changes in monetary policy are followed by significant exchange rate impact responses (Mueller et al., 2017; Tervala, 2019). On the other hand, monetary authorities committed to anchoring inflation expectations experience asymmetric exchange rate response under inflation surprises of equal magnitude (Arghyrou and Pourpourides, 2016; de Mendonca and Tiberto, 2017). Orlowski and Sywak (2019) examines the relationship between commodity futures and USD exchange rates and find that their interactions become positive at stressful market conditions, although that is pervasive inverse. From an international perspective, Lartey (2017) has explored the effects of capital inflows and the real exchange rate in emerging market economies and suggests that an increase in foreign direct investment (FDI) inflow would be associated with a greater appreciation of the real exchange rate under a higher level of financial openness. Additionally, exchange rates have a strong co-movement with other peer countries, and exchange rate uncertainty arises not only from shocks in individual markets but also from shocks transmitted across markets (Engle III et al., 1988; Özmen and Yılmaz, 2017; Tamakoshi and Hamori, 2014). However, previous studies have rarely considered the effect of EPU on the exchange rate volatility.

Within this body of literature, studies that focus on the EPU-the exchange rate volatility nexus are scarce. Empirically, Balcilar et al. (2016) and Kido (2016) find a significant contemporaneous or hysteresis relation between EPU and the exchange rate volatility. The key message from a related line of literature is that EPU has a heterogeneous impact on both times as well as space. Li et al. (2019) show that a positive or negative relationship between the EPU and exchange rates exist in Japan using the bootstrap rolling window sub-sample test, and find that the Yen appreciates when the EPU is increasing in crisis periods. Furthermore, the magnitude of the impact of EPU on the exchange rate volatility can vary across countries (Bartsch, 2019; Chen et al., 2019; Krol, 2014). The main contribution to this literature is to show that, the effects of EPU on exchange rates should not be underestimated. Theoretically, EPU has both direct and indirect impacts on exchange rate volatility. The greater EPU a country has, the faster exchange rates will change with a more flexible regime. Moreover, EPU influences the economy state, thereby impacting exchange rate volatility. Therefore, we explore the impact of EPU on exchange rate volatility.

There is a heterogeneous effect of EPU in different countries on China's exchange rate volatility. For one thing, we examine the distributional heterogeneous on the exchange rate volatility across various quantiles (Bao et al., 2018; Li et al., 2018; Liao et al., 2019). The impact of EPU is significantly for high quantiles, which implies that effects do not send the transmission to China during stable times of the exchange rate volatility (Patton, 2010). For another, we consider the effects of EPU in different countries the direction of the exchange rate volatility. Substantial effects of exchange rates may be due to different transmission mechanisms (Bildirici and Badur, 2018). For example, the effect is significantly negative for Singapore and Germany. Japan, the United States, and the United Kingdom EPU is a strongly positive impact on the exchange rate volatility of China.

The heterogeneous effect that we consider is associated with the bilateral relationship. The evidence also indicates that the degree of the exchange rate volatility might notably be attributed to interest rate difference or bilateral trading between China and other countries (Ames et al., 2017; Bahmani-Oskooee and Aftab, 2017; Dimitriou et al., 2017; Hurley and Papanikolaou, 2018; Lee and Werner, 2018; Yang and Gu, 2016). Given that interest rate parity and international trade play a role in the exchange rate volatility, which in turn, are subject to fluctuations caused by EPU in other countries, would suggest an indirect channel through which bilateral factors can affect the exchange rate volatility. In general, the change of EPU could impact various transmission mechanisms, thereby bringing about a heterogeneous role on the exchange rate volatility.

We make two primary contributions to the existing body of knowledge on this topic. First, no attempt has been made so far to examine the heterogeneous effect of EPU on the different distributions of the exchange rate volatility, something that one may find surprising, given the importance of exchange rate movements, and hence, this is what we aim to investigate in this paper. Second, this study assesses how EPU in different countries influenced the exchange rate volatility of China. We attempt to explore the transmission mechanism of heterogeneity by using the quantile regression model with interaction. And we find, except for direct impact, EPU has indirect impacts according to bilateral factors on the exchange rate volatility.

The remainder of this paper is organized in the following manner. Section 2 presents the hypotheses development. Section 3 offers evidence of the heterogeneous effect from different countries. Section 4 discusses the transmission mechanism of heterogeneous effect. Section 5 presents the conclusion and policy implication.

2. Hypotheses development

In this section, our objective is to propose and motivate the hypotheses we test in this paper. In particular, we have four hypotheses as follows:

Hypothesis 1. EPU has a significant impact on the exchange rate volatility.

Theoretically speaking, there is a significant impact on the exchange rate volatility following EPU shocks. The heterogeneous expectations among market participants have an effect on an asset's price. Uncertainty implies that participants update their beliefs concerning risk heterogeneously in time or direction (Bartsch, 2019). On one hand, EPU was measured using political events that influence the exchange rate volatility. EPU commands a significant positive risk in the volatility of exchange rates, even when controlling for other economic variables (Kido, 2016; Krol, 2014).

Greater EPU can increase the volatility of exchange rate market, which makes it riskier to purchasing exchange rates. On the other hand, changes in EPU can adversely affect the performance of an economy, which influences investors decision and provoke cooperation with countries, resulting in steady exchange rates and reducing the exchange rate volatility (Chen et al., 2019). Overall, relative changes of EPU can reflect the transaction risk associated with the international market.

Hypothesis 2. EPU for different countries affects China's exchange rate volatility at various quantiles differently.

There is a heterogeneous effect of EPU in different countries on China's exchange rate volatility. Nation strategy is one of the main culprits of heterogeneity. As for China, the decision related specifically to the policy of governments may impact financial markets (Brogaard and Detzel, 2015). The RMB exchange rate regime has been continuously adjusted to market-oriented. China has reformed the exchange rate regime allowing the RMB to float. In the high degree of marketization, the exchange rate market fully reflects all available information (Bray, 1981). Thus, the effect of EPU shock has an insignificant impact during periods of steady the exchange rate volatility. However, China is the largest current account surplus country in the world and the largest foreign exchange reserves (Yu, 2018). China has retained capital controls when the drastic volatility able to implement the controls effectively. If the government wishes to maintain the stability of exchange rates, it may have to intervene to ensure steady changes in exchange rates during higher volatility. Generally, the economy is able to exist co-movement, yet interdependencies might emerge (Balcilar et al., 2016). The co-movement of economies should be not neglected during the high volatility, because investors have comprehensive market information (Qin et al., 2018). EPU increasing will pass through in the market. When the exchange rate volatility is relatively high, EPU have a significant positive effect on the exchange rate volatility. In regard to regional cooperation countries, investors could be looking at the EPU of other important economies (i.e., the Belt and Road) in predicting the volatility (Balcilar et al., 2019). When the volatility is high, investors believe that is bull news on cooperation policy from nation strategy. When the volatility is low, investors do not seem to rely on any information associated with domestic global EPU.

Hypothesis 3. EPU affects the channels of the exchange rate volatility differently.

Bilateral trading and relative interest rate are mainly transmission mechanisms through which EPU can impact the exchange rate volatility. EPU changes affect interest rates or terms of trade. These economic variables affect the exchange rate market. Firstly, changes in bilateral trading from EPU changes are likely to affect the exchange rate volatility (Bahmani-Oskooee and Aftab, 2018; Narayan and Nguyen, 2016). The exchange rate volatility response to EPU depends on traders' risk attitude. The risk-averse trader will avoid trade in response to an increase in EPU fluctuations, while in response to a similar situation, the risk tolerant trader will increase trading to carry trade activities. That is, China's exchange rate tends to high volatility when bilateral trading increases. Therefore, it is the overall dominance of international trade market participants, which decides the ultimate impact of EPU through trade flows on the exchange rate volatility. Secondly, the relative interest rate would the other channel through which EPU can impact the exchange rate volatility. Common knowledge suggests that if interest rate in the foreign economy is higher than domestic interest rate at the drastic of the exchange rate volatility, then foreign investors would prefer to invest into assets denominated in the domestic currency, implying that the value of the domestic currency relative to the foreign

currency would appreciate, i.e., the volatility on domestic currency would be affected (Engel, 2016; Liu et al., 2017). Specifically, higher interest rate difference will stimulate the exchange rate volatility, and lower interest rate difference will slow it.

3. Heterogeneous effect from different countries

3.1. Quantile regression model

Most of the existing studies have adopted the traditional Econometric model to identify influencing factors for the exchange rate volatility, but this approach only provides the mean value of the dependent variable and fails to describe the whole picture of the conditional distribution. However, due to the tremendous heterogeneity in China develop, the relationships between EPU and volatility are likely to perform discriminately at different quantiles. Quantile regression (QR) has distinctive advantages of detecting the variation in the effect of EPU on the distribution of the exchange rate volatility and is able to help us obtain a more complete picture of the EPU affecting the exchange rate volatility. Specifically, we may assess how EPU shocks affect exchange rates according to their position on the conditional volatility distribution. Using this methodology, we are able to assess the heterogeneous effect of EPU throughout the conditional distribution, with a particular focus on a large the exchange rate volatility periods that are arguable of greatest interest. In the quantile regression framework, the focus is on the heterogeneous effect of the full distribution of the exchange rate volatility. Therefore, this paper adopts the quantile regression to comprehensively investigate the relationships between multiple EPU and the exchange rate volatility at different quantiles.

The quantile regression model can be written as:

$$Q_\tau(VOL|\mathbf{EPU}) = \alpha_0^\tau + \beta_1^\tau CN + \beta_2^\tau US + \beta_3^\tau JP + \beta_4^\tau SG + \beta_5^\tau KR + \beta_6^\tau DE + \beta_7^\tau UK + \beta_8^\tau VOL_{t-1} + \varepsilon_0^\tau \quad (1)$$

where $Q_\tau(VOL|\bullet)$ denotes a conditional quantile function of the exchange rate volatility evaluated at τ_{th} quantile, where $\tau \in (0,1)$ $\mathbf{EPU}$ is the vector of economic policy uncertainty indexes of different countries, including China (CN), the United States (US), Japan (JP), Singapore (SG), Republic of Korea (KR), Germany (DE) and the United Kingdom (UK). VOL_{t-1} is regressed on the lagged the exchange rate volatility of China and a vector of control variables.

The coefficients of the τ_{th} quantile of the conditional distribution is defined as a solution to the minimization problem (Koenker and Bassett, 1978).

$$\min_{\hat{\beta}_i^\tau}[\sum_{VOL \geq \alpha_0^\tau + \mathbf{EPU}\hat{\beta}_i^\tau} \tau \left| VOL - \alpha_0^\tau - \mathbf{EPU}'\hat{\beta}_i^\tau \right| + \sum_{VOL < \alpha_0^\tau + \mathbf{EPU}'\hat{\beta}_i^\tau} (1-\tau) \left| VOL - \alpha_0^\tau - \mathbf{EPU}'\hat{\beta}_i^\tau \right|] \quad (2)$$

where the coefficient vector β_i^τ will differ depending on the particular quantile being estimated. Given the exchange rate volatility, a higher estimated of β_i^τ increases effect of EPU.

3.2. The data

The data for our analysis consists of month the exchange rate volatility of China and the economic policy uncertainty index for the 7 countries chosen. The time period for the dataset spans from Jan, 2003 to Jan, 2019, which includes two landmark reform of the exchange rate regime. And we can comprehensively analyze the determinants of China's exchange rate market. As for the exchange rate volatility, real effective exchange rate, which is the weighted average of a country's currency relative to the basket of other major currencies, is obtained from China Stock Market & Accounting Research Database (CSMAR). And we applied the ARMA-GARCH volatility of exchange rates. As for EPU, we use the economic policy uncertainty indices for trading countries with China, that is, the United States, Japan, Singapore, Republic of Korea, Germany, and the United Kingdom. The selected partner countries represent the top six countries in trading with China and 72% of the total international trade volume in China. EPU measures of Baker et al. (2016) at their companion website (http: //www. policyuncertainty.com/). Since we want to compare the strengths of the various EPU in affecting the exchange rate volatility of China, we standardize the natural logarithmic values of the EPU by dividing with their respective standard deviations. In addition, one lagged of the exchange rate volatility is regarded as control variables. Volatility clustering refers to a situation that exists in exchange rate markets where large changes tend to be followed by large changes, and small changes tend to be followed by small ones (Rofael and Hosni, 2015). Therefore, we estimate specifications with a one-period lag of the exchange rate volatility (VOL_{t-1}), in order to capture market information.

Table 1 shows the summary statistics of the dependent and explanatory variables. With regard to dependent variables, the monthly level of the exchange rate volatility is 1.337 percent with a variation of 0.131. Furthermore, we focus on the EPU of different countries, which presents differences in mean values. For example, the mean of the Japan EPU is 15.497, whereas that of China is 6.843. In terms of volatility, a higher variation of EPU means that the series is more dispersed throughout the sample period than other countries. China has the highest volatility among the variables, which is 0.146. Comparatively, Japan has the least volatile EPU among the sample countries. Thus, the divergence of EPU across different regions is considerable, and there is a number of striking heterogeneities.

Table 1. Summary statistics.

Variable	N	Mean	Max.	Min.	Coef.var
VOL	193	1.337	2.120	1.245	0.099
CN	193	6.843	9.505	4.535	0.146
US	193	12.475	14.876	10.011	0.080
JP	193	15.497	18.421	13.089	0.065
SG	193	10.765	13.371	8.829	0.093
KR	193	11.339	14.076	8.532	0.088
DE	193	9.933	12.607	6.898	0.101
UK	193	7.363	10.059	4.882	0.136

3.3. Results

Conditional quantile estimates for the heterogeneity are also explored by performing QR. The result in Table 2 shows the heterogeneous effect of EPU on China's exchange rate volatility. In particular, one can distinguish countries into three groups. The first one includes China, the United States, Japan and the United Kingdom where a strongly significant positive linkage between the exchange rate volatility and EPU is revealed. The second group includes Singapore and Germany where one can find a negative dependence between EPU and the exchange rate volatility. The last group shows that the effects of Republic of Korea EPU on the exchange rate volatility in China are insignificant across all quantiles.

The impact of economic policy uncertainty on the exchange rate volatility is significantly positive in the first group. China EPU is insignificant at the lower volatility of exchange rates; however, it is positive and significant for the 50%, 75% and 90% quantile. In fact, the exchange rate regime of China carries out managed floating. To a certain extent, there are allowed the market to decide what should be the right level of exchange rates. Thus, it is natural to predict that the impact of China EPU will be mitigated when the volatility of exchange rate is stable. However, due to stability preference, the government would intervene to ensure changes in exchange rates during higher volatility. EPU reflects decision making in the government which should be enhanced during higher volatility of exchange rates. The effect of the United States economic policy uncertainty is negligible for all quantiles, except for the quantile 95%, which implies that economic policy uncertainty in the United States does not send the transmission to China during normal and stable times. Hence, there is tail dependence, indicating that extreme movements (positive or negative) of the United States economic policy uncertainty have an impact on the volatility of exchange rates in China. The economy's poor performance has been caused by an exogenous increase in US policy uncertainty. Considering changes in US EPU, investors may well come up with new decisions in the international market accordingly. Therefore, changes EPU in US are likely to influence the behavior of all investors who partake in the Chinese exchange rate markets. The positive and significant dependence between the Japanese economic policy uncertainty and the exchange rate volatility is evident for all quantiles, except for the quantile 5%, and the dependence intensifies across different quantiles. As the two largest influence Asian countries, Japan and China have the co-volatility effects on market participants across the financial markets. Thus, there is strong evidence that, the exchange rate volatility in China is the most sensitive to Japanese economic policy uncertainty. From the perspective of the United Kingdom where the impact of the economic policy uncertainty is positive and significant for the 5% and 95% quantiles. Asymmetric tail dependence is observed for these countries, even though the lower tail dependence significantly decreases with the stability of the exchange rate volatility.

Regarding the second group, the effects of economic policy uncertainty on the exchange rate volatility in China are negative and similar across the quantiles for Singapore and Germany economies, with dependence remaining almost constant across different quantiles. Singapore's EPU seems to be not related to exchange rates in the low volatility, the impact is only in the upper quantiles. Similarly, the effect is significantly negative for the intermediate and upper quantiles for Germany, underscoring the importance of economic policy uncertainty in the drastic volatility.

However, for lower quantiles, there is no significant impact of the EPU index on the exchange rate volatility in China, which implies that economic policy uncertainty in Germany does not get transmitted to China during the lower volatility periods. This result is consistent between Germany and Singapore that the economic policy uncertainty has a negative effect on higher volatility of exchange rate, which implies that economic diplomacy in different international environments can influence market volatility. Overall, this means that the dependence with respect to changes in the economic policy uncertainty is heterogeneous for these countries.

For Republic of Korea, the empirical results derived from QR estimations indicate that EPU shocks have no statistically significant general impacts on the exchange rate volatility of China. In fact, China has been the largest export market for KR, and China has had persistent trade surpluses with KR. Therefore, due to KR strong trade dependence on China, EPU for Republic of Korea has no significant impact on China's exchange rate volatility.

Table 2. Heterogeneous effect of EPU on China's exchange rate volatility.

Variable	5%	25%	50%	75%	95%
CN	0.0003	0.008	0.035*	0.082**	0.163**
	(0.001)	(0.007)	(0.019)	(0.040)	(0.074)
US	−0.0002	−0.002	0.004	0.013	0.102*
	(0.001)	(0.005)	(0.011)	(0.029)	(0.061)
JP	0.0005	0.008**	0.032***	0.079***	0.111**
	(0.0004)	(0.004)	(0.012)	(0.027)	(0.047)
SG	−0.001	−0.015	−0.060*	−0.178**	−0.305
	(0.002)	(0.014)	(0.036)	(0.083)	(0.231)
KR	−0.00004	−0.001	0.006	0.012	0.007
	(0.001)	(0.003)	(0.010)	(0.017)	(0.028)
DE	−0.0002	0.001	−0.012	−0.022	−0.129***
	(0.0005)	(0.004)	(0.012)	(0.024)	(0.035)
UK	0.001	0.005	0.010	0.046	0.193**
	(0.001)	(0.005)	(0.013)	(0.036)	(0.077)
VOL_{t-1}	0.003	0.028*	−0.018	0.176	0.612*
	(0.006)	(0.017)	(0.078)	(0.216)	(0.329)
Constant	1.240***	1.183***	1.153***	0.840**	−0.232
	(0.006)	(0.036)	(0.155)	(0.326)	(0.807)

Note: Statistical significance at the 10%, 5% and 1% levels are denoted by *, ** and ***, respectively.

4. Transmission mechanism of heterogeneous effect

As result in Section 3, there is a heterogeneous effect of EPU from different countries on China's exchange rate volatility and there is an interesting of understanding how heterogeneous effect comes up. Within this context, a study on the transmission mechanism of EPU across bilateral factor is worthwhile.

4.1. The model

We take into account the heterogeneity in the transmission mechanism of EPU. In fact, EPU is the main focus of the paper, bilateral trading and interest rate are used as channels through which EPU can influence the exchange rate volatility. This is consistent with the objective of the study which is to assess the indirect incidences of EPU on the exchange rate volatility. Therefore, we include interaction terms between EPU and bilateral variables that identify the transmission mechanism of heterogeneous effect in different countries. For this purpose, the basic model to be estimated in this paper is shown as (3).

$$VOL = \alpha_i^\tau + \delta_i^\tau \mathbf{EPU} + \gamma_i^\tau EPU_i * \mathbf{M} + \chi_i^\tau VOL_{t-1} + \varepsilon_i^\tau \tag{3}$$

where VOL refers to the exchange rate volatility; **EPU** is a vector of dependence variables to measure the EPU from sample countries; **M** is the transmission mechanism of EPU. VOL_{t-1} stands for control variables, and ε_i^τ is the error term.

In terms of **Hypothesis 3**, EPU from different countries affects the transmission mechanism of the exchange rate volatility differently. Since the channel of EPU shocks may vary throughout the distribution of the exchange rate volatility, we next use QR model that enables the study to assess the heterogeneity throughout the channel of the bilateral factor. In this sense, empirical models in this paper are shown as (4) and (5).

$$Q_\tau(VOL|EPU_i * BT_i) = \alpha_1^\tau + \delta_1^\tau CN + \delta_2^\tau US + \delta_3^\tau JP + \delta_4^\tau SG + \delta_5^\tau KR + \delta_6^\tau DE + \delta_7^\tau UK + \delta_8^\tau EPU_i * BT_i + \delta_9^\tau VOL_{t-1} + \varepsilon_1^\tau \tag{4}$$

$$Q_\tau(VOL|EPU_i * INR_i) = \alpha_2^\tau + \varphi_1^\tau CN + \varphi_2^\tau US + \varphi_3^\tau JP + \varphi_4^\tau SG + \varphi_5^\tau KR + \varphi_6^\tau DE + \varphi_7^\tau UK + \varphi_8^\tau EPU_i * INR_i + \varphi_9^\tau VOL_{t-1} + \varepsilon_2^\tau \tag{5}$$

where BT_i is a measure of the bilateral trading between China and trading partner i. INR_i represents the interest rate difference of China by i country. Both models entail interaction term, non-interaction terms elucidates direct effects of EPU on the exchange rate volatility, whereas

interaction term explains indirect impacts of EPU. δ_8^τ correspond to bilateral trading. In the same vein, φ_8^τ is related to interest rate difference.

4.2. The data

The transmission mechanism we employ are the two principal components of capital flow and invest arbitrage. Firstly, bilateral trading is represented by the capital flow. Bilateral trading is calculated as the ratio between monthly exports, the import price of China and each of the sample countries. While export is measured as net purchases of domestic (CN) goods and services by foreign residents, the import is the net purchases of foreign goods and services by domestic residents (CN). Thus, bilateral trading implies cross-border capital flow between China and regions. In terms of invest arbitrage, we use the difference between the log of China and others in the sample monthly lending interest rates. Positive numbers imply counterparties interest rate more than China and foreign investors would prefer to invest in assets denominated in the domestic currency. The sample period for this data is Jan 2003 to Jan 2019 and All data is obtained from the IMF's International Financial Statistics (IFS).

4.3. Results

Tables 3–4 provide the results of QR for the Unites States, Japan, Singapore, Germany, and the United Kingdom, which report the 5th, 25th, 50th, 75th and 95th percentiles of the exchange rate volatility distribution. Table 3 provides the results of EPU and the interaction between bilateral trading and EPU. Table 4 estimates the effects of EPU, interaction terms of interest rate difference and EPU. Statistical significance at the 10%, 5%, and 1% levels are denoted by *, ** and ***, respectively. Standard errors are in parentheses. Furthermore, the lower quantiles, such as the 5th, 25th refer to the exchange rate volatility with steady. The 50th quantiles refer to normal volatility. The higher quantiles, such as the 75th, and 95th refer to the volatility with drastic. Generally, the empirical results indicate that the impacts of influencing factors on the exchange rate volatility are clearly heterogeneous.

Comparing with Table 2, the interaction between bilateral trading and US EPU is significantly positive in the 5th quantile, while US EPU has a directly positive effect in the 95th quantile. The findings broadly show that for the steady of the exchange rate volatility, EPU can drive exchange rate through bilateral trading mechanisms (Caselli, 2019; Cheung et al., 2015; Dávalos, 2018; Santana-Gallego and Perez-Rodriguez, 2019). When the exchange rate volatility is steady, exchange rates are more sensitive to bilateral trading. The influence of bilateral trading between China and the US is found to be positive (and larger) for the exchange rate volatility of China. Here, an increase in EPU, which is a shock of market participants, leads to an increase (or decrease) in capital flow. And then capital inflows will cause the exchange rate volatility. When the exchange rate volatility is drastic, the possible explanation is economic integration that leads to close economic ties and changes in the international financial market brought about by the US economic state shocks, while EPU risks easily transmit from the US to others.

Table 3. Bilateral Trading, EPU and exchange rate volatility[1].

Variable	5%	25%	50%	75%	95%
US	−0.001*	−0.002	0.003	0.034	0.103
	(0.001)	(0.005)	(0.012)	(0.026)	(0.066)
$US*BT_{US}$	0.00005*	−0.0001	−0.001	−0.003	−0.003
	(0.00003)	(0.0003)	(0.001)	(0.002)	(0.005)
JP	−0.0003	0.008*	0.035***	0.077***	0.107*
	(0.0004)	(0.004)	(0.012)	(0.028)	(0.060)
$JP*BT_{JP}$	0.0003**	0.004***	0.005	0.001	−0.014
	(0.0001)	(0.001)	(0.004)	(0.010)	(0.021)
SG	0.001	−0.014	−0.065	−0.161	−0.427**
	(0.002)	(0.014)	(0.046)	(0.105)	(0.173)
$SG*BT_{SG}$	0.0001	0.001	0.004*	0.006	0.005
	(0.0001)	(0.001)	(0.002)	(0.004)	(0.006)
DE	−0.001	0.001	−0.017	−0.004	−0.085
	(0.001)	(0.005)	(0.011)	(0.025)	(0.054)
$DE*BT_{DE}$	0.0003	−0.001	0.003	−0.011	−0.013
	(0.0002)	(0.001)	(0.005)	(0.009)	(0.013)
UK	0.001	0.005	0.004	0.032	0.235***
	(0.001)	(0.004)	(0.014)	(0.025)	(0.065)
$UK*BT_{UK}$	−0.00001	−0.0004	−0.002	−0.003	−0.007
	(0.0001)	(0.0004)	(0.001)	(0.002)	(0.006)

[1]We introduce interaction between bilateral trading and EPU modeling for countries, but omits the results of other countries due to space limitations.

Table 4. Interest rate difference, EPU and exchange rate volatility[2].

Variable	5%	25%	50%	75%	95%
US	−0.00001	−0.002	0.001	0.016	0.060
	(0.001)	(0.005)	(0.010)	(0.030)	(0.079)
$US*INR_{US}$	0.00002	−0.0001	0.001	−0.001	0.007
	(0.0001)	(0.001)	(0.002)	(0.004)	(0.012)
JP	0.0005	0.008*	0.032*	0.078***	0.222***
	(0.001)	(0.004)	(0.017)	(0.030)	(0.051)
$JP*INR_{JP}$	0.0001	−0.0002	0.002	0.004	0.033***
	(0.0002)	(0.001)	(0.002)	(0.005)	(0.011)
SG	−0.0004	−0.012	−0.048	−0.177**	−0.371
	(0.002)	(0.015)	(0.042)	(0.081)	(0.338)
$SG*INR_{SG}$	−0.0002	0.001	0.005	0.010	0.014
	(0.0003)	(0.001)	(0.005)	(0.009)	(0.025)
DE	−0.0002	0.0002	−0.015	−0.020	−0.050
	(0.001)	(0.004)	(0.009)	(0.019)	(0.048)
$DE*INR_{DE}$	−0.00004	0.001	0.006	0.015	0.036
	(0.0004)	(0.002)	(0.006)	(0.012)	(0.036)
UK	0.001	0.009	0.032	0.038	0.301***
	(0.002)	(0.006)	(0.020)	(0.050)	(0.065)
$UK*INR_{UK}$	0.0001	0.001	0.002*	−0.001	0.012**
	(0.0001)	(0.0004)	(0.001)	(0.003)	(0.006)

As for Japan, there is an indirect positive effect of bilateral trading in the 5th and 25th quantiles, and interest rate difference in the 95th quantile. While there is a direct effect of EPU on the exchange rate volatility of China from the 25th quantile to the 95th quantiles. The more two countries are similar, in terms of factor endowment, the more they might correlation. The coefficient for EPU, is expected to be positive. Thence, EPU for Japan has a significantly positive on the exchange rate volatility of China in all quantiles, except the 5th quantile. As for the steady of volatility, bilateral

[2]We introduce interaction between interest rate difference and EPU modeling for countries, but omits the results of other countries due to space limitations.

trade flows brought by EPU between China and Japan leads to an increase in the exchange rate volatility. However, changes in EPU will advance venture capital during the higher volatility. The exchange rate volatility is likely to be enhanced when interest rates difference is bigger.

Regarding Singapore and Germany, it can observe that the effect of EPU is significantly negative. Specifically, there is a positive effect from the interaction between bilateral trading and EPU for Singapore is positive in the 50th quantile while a direct negatively effect from EPU for Singapore in the 95th quantile. Whereas EPU for Germany has a directly negative effect on the exchange rate volatility of China in the 95th quantile. A possible explanation for this tendency is that, when the volatility is normal, EPU for Singapore could affect bilateral trading which in turn increases (or decreases) the exchange rate volatility. It is important to note that EPU could directly negative affect the exchange rate volatility during the volatility is higher, which is appreciated as the confidence of market participants brought by government cooperation. The Belt and Road is a call of China for new modes of regional economic cooperation, which provoking cooperation between China and Singapore, Germany during the recent US-China Trade Dispute. This relation of trading leads to avoiding drastic volatility of exchange rates.

Finally, the results for the UK present that the EPU may directly affect the exchange rate volatility of China positively in the 95th quantile, and interest rate across EPU may indirectly affect the exchange rate volatility of China positively in the 50th and 95th quantiles. When the exchange rate volatility is drastic, EPU risk will be transmitted into the international market for exchange rates in order to affect its volatility. Economic explanations might be related to factors typically associated with currency speculation or carry-trades. A tendency for investors to reserve in high-yielding currencies in case of economic policy uncertainty events might reflect investment currency' appreciation. The higher interest rate difference will promote the exchange rate volatility.

5. Conclusions and policy implication

The importance of EPU is observed to determinants of the exchange rate volatility. We investigate the effect of EPU for different countries on the exchange rate volatility of China and utilize the quantile regression model, which considered unobserved individual and distributional heterogeneity. It explains the influence paths by the decomposing impact of EPU into two main channels, bilateral trading and interest rate difference effects, which can help us obtain a more comprehensive understanding of the effect of EPU on the exchange rate volatility of China.

There is a heterogeneous effect of EPU in different countries on China's exchange rate volatility. On one hand, the impact of EPU on the direction of the exchange rate volatility is mixed. Specifically, the effect of EPU on the exchange rate volatility of China is significantly positive in China, the United States, Japan, and the United Kingdom, and has no impact on Republic of Korea. EPU for Singapore and Germany may have a negative effect. On the other hand, EPU affects the exchange rate volatility across various quantiles differently. The impact of EPU for the United States, Germany, the United Kingdom on the exchange rate volatility is significant during the drastic volatility, but the impact of China, Japan, and Singapore exists the period of normal and drastic volatility.

Second, the EPU transmission mechanism is heterogeneous. EPU, which effects on bilateral trading and interest rate difference, may also have an indirect effect on the exchange rate volatility of

China in different quantiles. For the United State, Japan and Singapore, there is a positive effect from the interaction between EPU and bilateral trading during the volatility of steady. For Japan and the United Kingdom, a positive effect is apparent from the interaction between EPU and interest rate difference during the volatility of drastic.

In light of the above, the following policy implications could be made to decrease the exchange rate volatility in China. First, according to the direct and indirect influence mechanisms of EPU on the exchange rate volatility, control risks should be tailored discriminatively, especially the countries with the most effective. Second, considering that bilateral trading and interest rate difference by EPU will increase volatility, the government should encourage import and adjust the interest rate to decrease the EPU effect during the higher volatility. Third, China should simultaneously strengthen political cooperation with countries and provide confidence to market participants. In sum, the government can develop appropriate plans to reduce the exchange rate volatility according to the different periods of the exchange rate market.

There are a few potential types of research that can be considered the effect of EPU in the future. As part of, one could look at the impact of EPU on green innovation in enterprises, whether there is a moderating or mediating effect of the exchange rate, like in Li et al. (2018) and Huang et al. (2019). Furthermore, the other could take into account the effect between developed and developing countries exists heterogeneity (Li et al., 2019). Nevertheless, it could be used as an extension to our current analysis by looking at a broad sample of developed and developing countries.

Acknowledgments

This research was funded by National Office for Philosophy and Social Sciences, grant number "19BGL050". All the opinions expressed in the present paper are the authors' and should not be attributed to any organization that they are affiliated with.

Conflict of interest

The authors declare no conflict of interest.

References

Aastveit K, Natvik GJ, Sola S (2017) Economic uncertainty and the influence of monetary policy. *J Int Money Financ* 76: 50–67. doi:10.1016/j.jimonfin.2017.05.003

Akar C, Çi çek S (2015) "New" monetary policy instruments and the exchange rate volatility. *Empir* 43: 141–165. doi:10.1007/s10663-015-9298-y

Ames M, Bagnarosa G, Peters GW (2017) Violations of uncovered interest rate parity and international exchange rate dependences. *J Int Money Financ* 73: 162–187. doi:10.1016/j.jimonfin.2017.01.002

Arghyrou MG, Pourpourides P (2016) Inflation announcements and asymmetric exchange rate responses. *J Int Financ Markets Inst Money* 40: 80–84. doi:10.1016/j.intfin.2015.07.002

Arouri M, Estay C, Rault C, et al. (2016) Economic policy uncertainty and stock markets: Long-run evidence from the US. *Financ Res Lett* 18: 136–141. doi:10.1016/j.frl.2016.04.011

Bahmani-Oskooee M, Aftab M (2017) On the asymmetric effects of the exchange rate volatility on trade flows: New evidence from US-Malaysia trade at the industry level. *Econ Model* 63: 86–103. doi:10.1016/j.econmod.2017.02.004

Bahmani-Oskooee M, Aftab M (2018) Asymmetric effects of exchange rate changes on the Malaysia-China commodity trade. *Econ Syst* 42: 470–486. doi:10.1016/j.ecosys.2017.11.004

Bahmani-Oskooee M, Saha S (2019) On the effects of policy uncertainty on stock prices: an asymmetric analysis. *Quant Financ Econ* 3: 412–424. doi:10.3934/qfe.2019.2.412

Balcilar M, Gupta R, Kim WJ, et al. (2019) The role of economic policy uncertainties in predicting stock returns and their volatility for Hong Kong, Malaysia and South Korea. *Int Rev Econ Financ* 59: 150–163. doi:10.1016/j.iref.2018.08.016

Balcilar M, Gupta R, Kyei C, et al. (2016) Does Economic Policy Uncertainty Predict Exchange Rate Returns and Volatility? Evidence from a Nonparametric Causality-in-Quantiles Test. *Open Econ Rev* 27: 229–250. doi:10.1007/s11079-016-9388-x

Bao L, Zhao G, Jin Z (2018) A new equilibrium trading model with asymmetric information. *Quant Financ Econ* 2: 217–229. doi:10.3934/qfe.2018.1.217

Bartsch Z (2019) Economic policy uncertainty and dollar-pound exchange rate return volatility. *J Int Money Financ* 98: 102067. doi:10.1016/j.jimonfin.2019.102067

Beckmann J, Czudaj R (2017) Exchange rate expectations and economic policy uncertainty. *Eur J Polit Econ* 47: 148–162. doi:10.1016/j.ejpoleco.2016.06.003

Bray M (1981) Futures trading, rational expectations, and the efficient markets hypothesis. *Econometrica J Econometric Society,* 575–596. doi: 10.2307/1911513

Brogaard J, Detzel A (2015) The Asset-Pricing Implications of Government Economic Policy Uncertainty. *Manage Sci* 61: 3–18. doi:10.1287/mnsc.2014.2044

Caggiano G, Castelnuovo E, Figueres JM (2017) Economic policy uncertainty and unemployment in the United States: A nonlinear approach. *Econ Lett* 151: 31–34.

Caselli FG (2019) China's rise, asymmetric trade shocks and exchange rate regimes. *Rev Int Econ* 27: 1–35. doi:10.1111/roie.12353

Cebula RJ, Boylan R (2019) Uncertainty regarding the effectiveness of Federal Reserve monetary policies over time in the U.S.: an exploratory empirical assessment. *Quant Financ Econ* 3: 244–256. doi:10.3934/qfe.2019.2.244

Chen L, Du Z, Hu Z (2019) Impact of economic policy uncertainty on the exchange rate volatility of China. *Financ Res Lett.* doi:10.1016/j.frl.2019.08.014

Cheung YW, Chinn MD, Qian X (2015) China–US trade flow behavior: the implications of alternative exchange rate measures and trade classifications. *Rev World Econ*152: 43–67. doi:10.1007/s10290-015-0232-y

Christou C, Gupta R, Hassapis C (2017) Does economic policy uncertainty forecast real housing returns in a panel of OECD countries? A Bayesian approach. *Q Rev Econ Financ* 65: 50–60.

Dávalos J (2018) Trade openness effects on informality and the real exchange rate channel. *Appl Econ Lett* 26: 506–510. doi:10.1080/13504851.2018.1486982

de Mendonca HF, Tiberto BP (2017) Effect of credibility and exchange rate pass-through on inflation: An assessment for developing countries. *Int Rev Econ Financ* 50: 196–244. doi:10.1016/j.iref.2017.03.027

Dimitriou D, Kenourgios D, Simos T (2017) Financial crises, exchange rate linkages and uncovered interest parity: Evidence from G7 markets. *Econ Model* 66: 112–120. doi:10.1016/j.econmod.2017.06.003

Engel C (2016) Exchange Rates, Interest Rates, and the Risk Premium. *Am Econ Rev* 106: 436–474. doi:10.1257/aer.20121365

Engle III RF, Ito T, Lin WL (1988) Meteor showers or heat waves? Heteroskedastic intra-daily volatility in the foreign exchange market. National Bureau of Economic Research Cambridge, Mass., USA.

Fang L, Chen B, Yu H, et al. (2018) The importance of global economic policy uncertainty in predicting gold futures market volatility: A GARCH-MIDAS approach. *J Futures Mark* 38: 413–422. doi:10.1002/fut.21897

Gantman ER, Dabós MP (2017) International trade and factor productivity as determinants of the real effective exchange rate. *Appl Econ Lett* 25: 331–334. doi:10.1080/13504851.2017.1321829

Huang Z, Liao G, Li Z (2019) Loaning scale and government subsidy for promoting green innovation. *Technol Forecast Soc Chang* 144: 148–156, doi:10.1016/j.techfore.2019.04.023.

Hurley DT, Papanikolaou N (2018) An Investigation of China-U.S. Bilateral Trade and Exchange Rate Changes Using the Autoregressive Distributed Lag Model. *Econ Pap J Appl Econ Policy* 37: 162–179. doi:10.1111/1759-3441.12206

Jones PM, Olson E (2013) The time-varying correlation between uncertainty, output, and inflation: Evidence from a DCC-GARCH model. *Econ Lett* 118: 33–37. doi: https://doi.org/10.1016/j.econlet.2012.09.012

Kido Y (2016) On the link between the US economic policy uncertainty and exchange rates. *Econ Lett* 144: 49–52. doi:10.1016/j.econlet.2016.04.022

Ko JH, Lee CM (2015) International economic policy uncertainty and stock prices: Wavelet approach. *Econ Lett* 134: 118–122. doi:10.1016/j.econlet.2015.07.012

Koenker R, Bassett G (1978) Regression quantiles. *Econometrica* 46: 33–50. doi: 10.2307/1913643

Krol R (2014) Economic Policy Uncertainty and The exchange rate volatility. *Int Financ* 17: 241–256. doi:10.1111/infi.12049

Lartey EKK (2017) Fdi, Sectoral Output And Real Exchange Rate Dynamics Under Financial Openness. *Bull Econ Res* 69: 384–394. doi:10.1111/boer.12075

Lee KS, Werner RA (2018) Reconsidering Monetary Policy: An Empirical Examination of the Relationship Between Interest Rates and Nominal GDP Growth in the U.S., U.K., Germany and Japan. *Ecol Econ* 146: 26–34. doi:10.1016/j.ecolecon.2017.08.013

Li XM, Peng L (2017) US economic policy uncertainty and co-movements between Chinese and US stock markets. *Econ Model* 61: 27–39. doi:10.1016/j.econmod.2016.11.019

Li XM, Zhang B, Gao R (2015) Economic policy uncertainty shocks and stock–bond correlations: Evidence from the US market. *Econ Lett* 132: 91–96. doi:10.1016/j.econlet.2015.04.013

Li Z, Dong H, Huang Z, et al. (2018) Asymmetric Effects on Risks of Virtual Financial Assets (VFAs) in different regimes: A Case of Bitcoin. *Quant Financ Econ* 2: 860–883. doi:10.3934/qfe.2018.4.860

Li Z, Dong H, Huang Z, et al. (2019) Impact of Foreign Direct Investment on Environmental Performance. *Sustainability* 11: 3538. doi:10.3390/su11133538

Li ZZ, Xiong DP, Daniela L, et al. (2019) HOW DOES ECONOMIC POLICY UNCERTAINTY EFFECT SIGNALING EXCHANGE RATE IN JAPAN? *Econ Comput Econ Cybern Stud Res* 53. doi:10.24818/18423264/53.1.19.09

Li ZH, Liao GK, Wang ZZ, et al. (2018) Green loan and subsidy for promoting clean production innovation. *J Clean Prod* 187: 421–431. doi:10.1016/j.jclepro.2018.03.066

Liao G, Li Z, Du Z, et al. (2019) The Heterogeneous Interconnections between Supply or Demand Side and Oil Risks. *Energies* 12: 2226. doi:10.3390/en12112226

Liu L, Zhang T (2015) Economic policy uncertainty and stock market volatility. *Financ Res Lett* 15: 99–105. doi:10.1016/j.frl.2015.08.009

Liu LX, Shu H, Wei KCJ (2017) The impacts of political uncertainty on asset prices: Evidence from the Bo scandal in China. *J Financ Econ* 125: 286–310. doi:10.1016/j.jfineco.2017.05.011

Mueller P, Tahbaz-Salehi A, Vedolin A (2017) Exchange Rates and Monetary Policy Uncertainty. *J Financ* 72: 1213–1252. doi:10.1111/jofi.12499

Narayan S, Nguyen TT (2016) Does the trade gravity model depend on trading partners? Some evidence from Vietnam and her 54 trading partners. *Int Rev Econ Financ* 41: 220–237. doi:10.1016/j.iref.2015.08.010

Özmen MU, Yılmaz E (2017) Co-movement of exchange rates with interest rate differential, risk premium and FED policy in "fragile economies". *Emerg Mark Rev* 33: 173–188. doi:10.1016/j.ememar.2017.10.007

Patton AJ (2010) Modelling Asymmetric Exchange Rate Dependence. *Int Econ Rev* 47: 527–556. doi:10.1111/j.1468-2354.2006.00387.x

Phan DHB, Sharma SS, Tran VT (2018) Can economic policy uncertainty predict stock returns? Global evidence. *J Int Financ Mark Inst Money* 55: 134–150. doi:10.1016/j.intfin.2018.04.004

Qin F, Zhang J, Zhang Z (2018) RMB Exchange Rates and Volatility Spillover across Financial Markets in China and Japan. *Risks* 6: 120. doi:10.3390/risks6040120

Rodrik D (2008) The real exchange rate and economic growth. *Brook Pap Econ Act* 39: 365–412.

Rofael D, Hosni R (2015) Modeling Exchange Rate Dynamics in Egypt: Observed and Unobserved Volatility. *Modern Econ* 06: 65–80. doi:10.4236/me.2015.61006

Santana-Gallego M, Perez-Rodriguez JV (2019) International trade, exchange rate regimes, and financial crises. *North Am J Econ Financ* 47: 85–95. doi:10.1016/j.najef.2018.11.009

Scheffel EM (2016) Accounting for the political uncertainty factor. *J Appl Econom* 31: 1048–1064.

Shahzad SJH, Raza N, Balcilar M, et al. (2017) Can economic policy uncertainty and investors sentiment predict commodities returns and volatility? *Resour Policy* 53: 208–218. doi:10.1016/j.resourpol.2017.06.010

Stauvermann PJ, Kumar RR, Shahzad SJH, et al. (2018) Effect of tourism on economic growth of Sri Lanka: accounting for capital per worker, exchange rate and structural breaks. *Econ Change Restructuring* 51: 49–68. doi:10.1007/s10644-016-9198-6

Sun X, Yao X, Wang J (2017) Dynamic interaction between economic policy uncertainty and financial stress: A multi-scale correlation framework. *Financ Res Lett* 21: 214–221. doi:10.1016/j.frl.2016.12.010

Orlowski LT, Sywak M (2019) Wavering interactions between commodity futures prices and us dollar exchange rates. *Quant Financ Econs* 3: 221–243. doi:10.3934/qfe.2019.2.221

Tamakoshi G, Hamori S (2014) Co-movements among major European exchange rates: A multivariate time-varying asymmetric approach. *Int Rev Econ Financ* 31: 105–113. doi:10.1016/j.iref.2014.01.016

Tervala J (2019) US monetary policy and China's exchange rate policy during the great recession. *Int J Financ Econ* 24: 113–130. doi:10.1002/ijfe.1652

Tsai IC (2017) The source of global stock market risk: A viewpoint of economic policy uncertainty. *Econ Model* 60: 122–131. doi:10.1016/j.econmod.2016.09.002

Wang Y, Zhang B, Diao X, et al. (2015) Commodity price changes and the predictability of economic policy uncertainty. *Econ Lett* 127: 39–42.

Yang G, Gu Q (2016) Effects of exchange rate variations on bilateral trade with a vehicle currency: Evidence from China and Singapore. *J Int Money Financ* 68: 50–73. doi:10.1016/j.jimonfin.2016.06.010

Yu YD (2018) The Long-Drawn Process of reform of the Exchange Rate Regime and the Evolution of China's Exchange Rate Policy. *China Econ J* 11: 284–300. doi:10.1080/17538963.2018.1512542

Li ZZ, De-Ping X, Lavinia Daniela M, et al. (2019) How Does Economic Policy Uncertainty Effect Signaling Exchange Rate in Japan? *Econ Comput Econ Cybern Stud Res* 53: 141–156. doi:10.24818/18423264/53.1.19.09

AIMS Press