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Analyzing exchange rate uncertainty and bilateral export growth in China: A multivariate GARCH-based approach☆

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ABSTRACT

Dramatic changes to exchange rate policy for the world's largest exporter have arguably ushered in the optimal environment for studying the effects of exchange rate uncertainty on trade. This study builds on the recent literature by using an extremely general model that measures volatility using the flexible multivariate DCC-GARCH model to analyze the impact exchange rate uncertainty has on bilateral export growth for China's ten largest export markets. All model parameters are estimated simultaneously and lagged values of uncertainty are included for a full year, where significant effects are found. The more general methods potentially overcome issues associated with inefficient two-step methods and the assumption that volatility impacts are close to instantaneous. Using a comprehensive sample that spans 1994–2017, the paper presents evidence that exchange rate uncertainty has no impact on trade with the United States, which strongly contrasts a robust finding of trade deterring impacts for almost all remaining countries. The unifying methodology is also used to analyze nominal uncertainty itself. Here, it is found that Chinese inflation may be a positive contributor to risk in an environment where many exogenous events, such as the Asian currency crisis, are associated with periods of heightened yuan uncertainty.

1. Introduction

Volatility and uncertainty may foment an environment where distortions and risk aversion have implications for resource allocation and economic trade. It is not surprising, therefore, that academicians and policy makers alike have devoted themselves to understanding the consequences of uncertainty for many economic variables including output, inflation, and, in an international setting, exchange rates. Policy makers in open economies that are reliant on international trade struggle particularly with managing the exchange rate, with implications for both monetary policy and the optimal choice of an exchange rate regime.

In understanding how uncertainty affects trade, China is arguably the world's most compelling country to study. By almost any metric, China is the largest exporter of goods and has an exchange rate policy that has undergone fascinating changes since restructuring in 1979 under Deng Xiaoping. China's currency, the yuan or RMB, has gradually moved from being tightly regulated without use outside of China, to a more market-oriented international currency. In fact, Clark (2017) shows that roughly 95% of changes in China's daily dollar parity rate can now be modeled as a simple function of changes in an index of cross-currency dollar rates and the previous day's closing price, implying these changes are largely in line with market forces. As the RMB emerges as one of the world's most important currencies, it is quite clear that uncertainty regarding its movement will emerge as a reality that market participants and policy makers must manage.

Against the backdrop of increasing RMB volatility, this article contributes in a number of ways to the literature analyzing the consequences of yuan uncertainty on bilateral trade using a very general model. The proposed method calculates uncertainty using the dynamic conditional correlation (DCC) specification of Engle (2002), which allows for potentially idiosyncratic choices for the conditional variances. In this context, asymmetry is analyzed in the measure of currency uncertainty to allow for differential effects of unexpected yuan strength versus weakness. Further, to avoid the use of two-step procedures that dominant the Chinese-based literature, all model parameters are estimated simultaneously, and a full year of lagged uncertainty effects are included. The inclusion of lagged effects of risk accommodates the delay between contracting and delivery of goods

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and proves to be an important innovation that is new to the literature. Further, subsample analysis is conducted for the period after the dollar peg ended in 2005, and both the nominal and real exchange rate are considered, so as to avoid much of the confusion that exists in the literature regarding the measurement choice of relative prices.

To preview, for the baseline results there is evidence that either nominal or real exchange rate uncertainty has a negative, statistically significant impact on export growth for almost all of China's trading partners. The exception is the United States, where there is no evidence that export growth is harmed by volatility. This helps bridge a gap in the literature, where most of the existing studies analyzing China focus on the US or use multilateral exports. It also has policy implications for China, given the historical choice to smooth primarily dollar-based exchange rate movements. As RMB internationalization is realized, the findings suggest volatility will have impacts on how yuan settlement affects trade with countries other than the US. Further, across a variety of models, compatibility between the findings based on the real versus nominal exchange rate suggests that most of the trade deterring effects arise from the nominal rate. The results using the most recent subsample generally confirm the negative impacts of uncertainty on China's trade with the eurozone, Hong Kong, India, and Korea. Finally, given the evidence that currency risk can cause a decline in trade, the unifying methodological approach is used to study the potential causes of RMB volatility. The results show that inflation may increase uncertainty in an environment where potentially exogenous events, such as the collapse of Lehman Brothers, dominate currency risk.

The rest of the paper is organized as follows. Section 2 surveys the literature analyzing the nexus between exchange rate uncertainty and trade with an emphasis on China's trade with the rest of the world. Section 3 describes the data and provides a preliminary discussion of the modeling choices that were made on the basis of unit root and heteroskedasticy testing procedures. Section 4 introduces the multivariate model used and the estimation algorithm that was employed to accomplish joint estimation of all parameters. The fifth section contains the results of estimation and a summary of major findings, and section 6 provides an analysis of the factors impacting RMB uncertainty. A final section concludes.

2. Literature review

Theoretical contributions have shown that exchange rate risk can generate both a positive and negative impact on trade. Early studies, such as Ethier (1973), build partial equilibrium models and use intuition in showing that risk-averse firms reduce exports when facing volatile revenues caused by exchange rate risk. On the other hand, DeGrauwe (1988) considers a model where a domestic firm using a fixed supply of resources splits production between home and foreign markets and shows trade could increase with currency uncertainty, the only source of risk for the firm. If the firm is very risk-averse, the marginal utility of profit can increase as exchange rate risk rises, causing production to increase. The resulting increase in exports would smooth revenue in the event adverse exchange rate shocks reduce the effective price.[1]

As discussed by McKenzie (1999) and more recently Asteriou et al. (2016), the empirical literature has failed to resolve the lack of clarity found in theoretical results, especially when looking at trade for developed economies. In this vein, more recent literature has analyzed emerging economies, where countries with less mature financial markets may be more dependent on exports. For example, Grier and Smallwood (2007) show a marked difference in the response of export growth to uncertainty for "rich" economies, where results are generally mixed or insignificant, versus those for developing economies where trade damaging effects are found. Asteriou et al. (2016) also document negative impacts for the exports and imports of developing economies, in this case for Mexico and Indonesia, using cointegration bounds testing procedures for both the real and nominal exchange rates. Using the DCC model, and allowing for asymmetric effects in the response of exports, Fang et al. (2009) provide evidence of strong trade deterring exchange rate volatility effects during depreciations for 4 of the 7 developing Asian economies in their sample.

For China specifically, several existing studies, including Chit et al. (2010), Caglayan et al. (2013), and Tang (2014), provide evidence that volatility eroded export growth using panel data that includes China. For studies that analyze Chinese exports individually, the evidence using two-step procedures based on cointegration methods and autoregressive distributed lag testing procedures has been mixed, especially when concentrating on trade with the US. Chou (2000) provides an important early study and finds evidence of negative short-run effects for three of the five industries investigated, with little evidence of a long-run volatility-export link. In analyzing bilateral exports with the US, Baak (2008) unearths a statistically significant negative connection when considering a restricted sub-sample since 1995, although there is no evidence of a link for the full sample. Huchet-Bouron and Korinek (2011) consider bilateral agricultural and merchandise exports for each pair involving China, the Economic and Monetary Union of Europe (EMU), and the US and generally fail to find a definitive short or long-run relationship. Nishimura and Hirayama (2013) also document little influence of direct volatility on exports from China to Japan, although they provide compelling evidence, both in the short and long-run, that uncertainty exerts a differential and statistically negative impact for the recent exchange rate reform period after 2005. Yang and Gu (2016) analyze the impact of using a vehicle currency, such as the US dollar, on the trade-uncertainty nexus for China and Singapore and also find evidence that the interaction between volatility and China's currency reform negatively affects exports in the long run.

3. Data and econometric issues

In the context of a multivariate system, specific interest here lies in the dynamics associated with exports. One of the most common econometric methodologies in the uncertainty based literature treats exports as a function of foreign income, the real exchange rate and its associated uncertainty. This specification, which is also used here, is founded on the two-good Bickerdike-Robinson-Metzler imperfect substitutes model.[2] The importance of lagged effects in this context is studied by Klaassen (2004). In his model, $P_{X,t}$, P_t, and P_t^F denote the price of a good in the exporting firm's currency, and the price levels in the exporting and importing country, respectively. Exporting firms, who care only about the real price, receive $P_{X,t}/P_t$ j-periods after contracting with a foreign buyer. The importer purchases goods to meet expected orders based on foreign income, Y_{t-k}^F, at some time $t-k$ between contracting date, $t-j$, and delivery date, t. Upon delivery, in real terms, she pays $P_{X,t}S_t/P_t^F$, for imports, with S_t denoting the nominal importer price of the exporter's currency.[3] All variables are known or can be forecasted perfectly, except the real exchange rate, such that demand is a function of the expected real exchange rate, $E_{t-j}R_t$, and its variance, $V_{t-j}R_t$. Setting demand equal to supply and solving for the real price of exported goods yields an export equation that is positively related to foreign income, Y_{t-k}^F, and is a function of the expected real exchange

[1] As discussed in the survey of McKenzie (1999), the early theoretical literature generally yields ambiguous predictions regarding the impact of uncertainty. More recently, Bacchetta and van Wincoop (2000) provide general-equilibrium guidance and show that the level of trade depends on monetary policy rules and is not necessarily higher under pegged exchange rates.

[2] Examples of studies using this empirical specification in the context of multivariate analysis include Fang et al. (2009), Baum and Caglayan (2010), and Grier and Smallwood (2013).

[3] With R_t denoting the real exchange rate defined as S_tP_t/P_t^F the importer pays $R_tP_{X_t}/P_t$ for imported goods.

rate, $E_{t-j}R_t$ and its variance $V_{t-j}R_t$. Increases in $E_{t-j}R_t$ increase the cost of imported goods and are expected to decrease exports, while, as discussed above, the volatility effects on trade are ambiguous.

We turn now to the data employed in this study. To analyze the potential idiosyncratic impact of exchange rate uncertainty for different export markets, estimation occurs for bilateral exports for each of China's ten most important markets, including the US, Hong Kong, Japan, South Korea, Germany, Vietnam, India, Netherlands, the UK, and Singapore.[4] Export data in thousands of US dollars are from the General Administration of Customs for China and are deflated using China's export price index collected from their National Bureau of Statistics. The original exchange rates are the end of the month national currency quotes of the US dollar, collected from WM/Thomson Reuters.[5] Non-seasonally adjusted consumer price indices were collected from the OECD and various national sources, such as the Bureau of Labor Statistics. The real exchange rate (RER) for China is calculated as the nominal price of the RMB multiplied by the ratio of China's price index relative to the price index of each trading partner. To proxy national income, given a monthly frequency, industrial or manufacturing production data was collected using Datastream for each country, again using national sources and the OECD.[6]

Export data are measured both in yuan and in the currency of China's trading partner, which allows for different assumptions regarding currency invoicing and adds to the literature studying currency choice, most notably Yang and Gu (2016). The baseline results cover the assumption of RMB invoicing, which can also be justified if a vehicle currency such as the dollar is used. If the dollar is used, exchange rate risk affects both exporters, who are concerned with movements in the yuan against the US dollar, and importers, who care about the movement in their currency against the dollar. Here, the variance of the exchange rate used in the baseline case is directly related to the variance of the exchange rate exporters care the most about (dollar price of the RMB) and the variance of the exchange rate relevant for importers (foreign currency price of the dollar). Finally, for portions of the sample where the RMB was pegged to the dollar, movements in the foreign currency price of the yuan could serve as a proxy for changes in the US dollar price of the yuan.

The time series characteristics of the variables used in this study were evaluated using standard unit root and cointegration tests. To summarize the results, which are available upon request, a near unanimous failure to reject the unit root null occurs for the logs of exports, foreign income, and both exchange rate variables. For these variables, we also generally fail to reject the no cointegration null using the algorithm of Johansen (1991). Although asymptotic theory for unit root and cointegration tests has not been fully developed in the current context, for the uncertainty variables generated in this study, the use of Dickey-Fuller based unit root tests results in near unanimous rejection of the I(1) null.[7] Based on the analysis here, coupled with the precedent established in the literature, including Baum and Caglayan (2010), uncertainty variables are assumed to be stationary and all remaining variables are I(1) without cointegration. This necessitates estimation in difference form for all series except the exchange rate uncertainty variables.

As a precursor to the multivariate analysis, individual AR-GARCH equations were fit for all variables using the T-GARCH specification of Glosten et al. (1993). The results provide strong evidence of heteroskedasticy in nearly every case, with additional evidence of asymmetric impacts for most exchange rate specifications as further discussed below. To motivate the use of a multivariate GARCH model, the spectral-based portmanteau tests of Duchesne and Lalancette (2003) were applied to the 3x1 disturbance vector, denoted $\widehat{\mathbf{U_t}}$, from an estimated homoskedastic VAR for the growth rates of exports, foreign income, and the relevant exchange rate. With $Z_t = vech(\widehat{\mathbf{U_t}}\widehat{\mathbf{U_{t'}}})$, where *vech* denotes the half-vectorization operator, the test statistic requires the estimated autocovariance matrix of Z_t at lag j given by $\Gamma_{\hat{Z}}(j)$, along with the kernel, $k()$ and associated bandwidth, m, used in spectral estimation. Under the null of no multivariate ARCH effects and with T and d denoting the sample size and number of elements of Z_t, the resulting test statistic, $T_T(k,m)$, has a standard normal distribution and is given as follows[8]:

$$T_T(k,m) = \frac{T\sum_{j=1}^{T-1} k^2(j/m) trace[\Gamma_{\hat{Z}}(0)^{-1}\Gamma_{\hat{Z}}(j)\Gamma_{\hat{Z}}(0)^{-1}\Gamma_{\hat{Z}}(j)'] - d^2 M_T}{(2d^2 V_T)^{1/2}}, \tag{3.1}$$

$$M_T = \sum_{j=1}^{T-1}(1-j/T)k^2(j/m),$$

$$V_T = \sum_{j=1}^{T-2}(1-j/T)[1-(j+1)/T]k^4(j/m).$$

The test results of Duchesne and Lalancette (2003) can be found in Table 1. Two separate VARs are estimated for each trading partner, including a VAR using the RER and one for the NER. Across all 20 tests, rejection occurs using a 1% test size, except in the case of the RER system for Hong Kong, where the test statistic of 2.432 yields rejection at the 5% level. The tests provide very strong support for the existence of multivariate ARCH effects for every country, which forms the basis for measuring uncertainty and estimating its impact on bilateral Chinese trade described in the following section.

4. The multivariate model

This section presents the model used in the analysis. The selected multivariate GARCH model is the flexible dynamic conditional correlation (DCC) method pioneered by Engle (2002). The DCC model is especially useful in the current context as it allows for idiosyncratic GARCH equations for each variable and also possesses a time varying conditional correlation matrix between disturbances.

Here, the 3 × 1 vector W_t contains the growth rates of bilateral exports, ΔX_t, industrial production for China's trading partner (ΔY_t^*), and the relevant exchange rate, either a real (ΔR_t) or nominal exchange rate, (ΔN_t). For a square matrix A, diag(A) denotes the vector that results from diagonal stacking. $Dg(A)$ sets the off-diagonal elements of A to zero, and the inverse of the square root of these quantities results when using $Dg(A)^{-1/2}$. Finally, with Ω_t denoting the information set at time t, and for the specification involving nominal exchange rates, the system is defined as follows

$$W_t = C + \sum_{j=1}^{P}\Phi_j W_{t-j} + \sum_{j=1}^{12}\Lambda_j \operatorname{diag}(D_{t-j}) + U_t,$$

$$U_t = [u_{X,t}, u_{Y^*,t}, u_{N,t}]', \tag{4.1}$$

[4] These countries represent China's largest trading partners for 2016 in terms of sales according to the World Bank (source: wits.worldbank.org/CountryProfile/en/Country/CHN/Year/2016/TradeFlow/EXPIMP/Partner/by-country).

[5] Exchange rates for Germany and the Netherlands use the original conversion rates of DEM 1.95583 and NLG 2.2037 and the end of the month euro price of the dollar to calculate the legacy currency value against the US dollar.

[6] Lacking monthly data, a cubic spline was fit to Vietnam's GDP to obtain an interpolation yielding monthly values. Finally, the Census X-12 seasonal filter was used for any data whose autocorrelation function exhibited seasonal patterns.

[7] For a recent discussion of unit root and cointegration tests in the context of GARCH disturbances, see Francq and Zakoian (2012) and Cavaliere et al. (2010).

[8] Here, the Daniell kernel is used and m is selected via cross-validation as discussed in Robinson (1991). See Duchesne and Lalancette (2003) for additional details for these tests.

Table 1
Tests for multivariate ARCH effects.

Country	T_T VAR(RER)	Optimal-m VAR(RER)	T_T VAR(NER)	Optimal-m VAR(NER)
Germany	18.5310***	3	18.9426***	3
p-value	[0.0000]		[0.0000]	
Hong Kong	2.4320**	3	5.5737***	3
p-value	[0.0150]		[0.0000]	
India	11.0040***	4	8.6737***	4
p-value	[0.0000]		[0.0000]	
Japan	9.7408***	3	8.9534***	3
p-value	[0.0000]		[0.0000]	
Korea	16.8976***	3	16.5618***	3
p-value	[0.0000]		[0.0000]	
Netherlands	16.3700***	4	13.9606***	3
p-value	[0.0000]		[0.0000]	
Singapore	9.2311***	3	11.1788***	3
p-value	[0.0000]		[0.0000]	
United Kingdom	3.6476***	6	3.9544***	6
p-value	[0.0002]		[0.0001]	
United States	8.8095***	3	7.6428***	3
p-value	[0.0000]		[0.0000]	
Vietnam	2.8929***	2	2.9026***	2
p-value	[0.0038]		[0.0037]	

(***), (**) Denotes rejection of the null hypothesis of no multivariate ARCH effects at the 1% and 5% levels.
Notes: The results here are for the tests of Duchesne and Lalancette (2003) that allow for multivariate ARCH effects of an unspecified form under the alternative hypothesis. The test statistic, denoted T_T, has a standard normal distribution under the null. The test statistic requires the selection of a bandwidth parameter, denoted "Optimal-*m*" and is calculated using the cross-validation procedure of Robinson (1991).
The results in columns 2–3 are obtained using the residuals from a reduced form VAR applied to the growth rates of bilateral exports from China for the listed country, foreign industrial production, and the real exchange rate, where lags were selected via minimization of the multivariate Schwarz Bayesian information criteria. The results in the last two columns are obtained from a similar VAR, with the growth rate of the nominal exchange rate replacing the growth rate of the real exchange rate. Maximum data availability is used, resulting in a sample, before differencing, running from January 1994 through April 2017 for Germany, Japan, Korea, Singapore, the United Kingdom, and the United States. The data for the Netherlands starts in January 1995, and, for Hong Kong, it ends in February 2017. The sample for India runs from April 1994 through March 2017, whereas the sample for Vietnam is the most limited, with available data from September 2000 through March 2017.

$$\text{where } U_t \mid \Omega_{t-1} \sim N(0, H_t), H_t = D_t \mathcal{P}_t D_t, \text{ and } \epsilon_t = D_t^{-1} U_t, \tag{4.2}$$

$$\Lambda_j = \begin{bmatrix} 0 & 0 & \lambda^{(j)}_{X,h_{N,N}} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}, D_t = \begin{bmatrix} h^{1/2}_{XX,t} & 0 & 0 \\ 0 & h^{1/2}_{Y^*Y^*,t} & 0 \\ 0 & 0 & h^{1/2}_{NN,t} \end{bmatrix}, \tag{4.3}$$

$$h_{ii,t} = \kappa_i + \alpha_i u^2_{i,t-1} + \delta_i h_{ii,t-1} + \tau_i I_{\{u_{i,t-1}<0\}} u^2_{i,t-1}, \quad i = X, Y^*, N. \tag{4.4}$$

An equivalent system is estimated in each case using RER growth in place of NER growth. For GARCH equations in (4.4), asymmetry is excluded in instances where τ_i was insignificant based on pre-testing. As in Engle (2002), where $\mathcal{P}$ is the unconditional correlation matrix of ϵ_t, Q_t and P_t are given as follows:

$$Q_t = (1 - a - b)\mathcal{P} + a\epsilon_{t-1}\epsilon'_{t-1} + bQ_{t-1},$$

$$\mathcal{P}_t = Dg(Q_t)^{-1/2} Q_t Dg(Q_t)^{-1/2}. \tag{4.5}$$

QMLE methods are used to estimate the system in (4.1)–(4.5), where P is selected via the multivariate Bayesian information criteria. With θ denoting the full set of parameters in the multivariate DCC-GARCH specification, and for a system with 3 variables, the unrestricted objective function becomes,

$$L_U(\theta; W_t) = -\frac{1}{2}\sum_{t=1}^{T}(3\log 2\pi + logdetH_t + U'_t H_t^{-1} U_t). \tag{4.6}$$

QMLE estimates of all model parameters are consistent, as discussed by Engle (2002), allowing for the use of valid testing procedures for parameter restrictions based on likelihood ratio test statistics. The specific hypothesis of interest here is that uncertainty fails to influence export growth. To obtain the relevant test statistic, the system of equations above is estimated without any feedback from GARCH equations to mean equations, yielding a restricted value for the likelihood function given by L_R. This value is used to form a test statistic that is distributed as a $\chi^2(12)$ random variable, and is given by $2(L_U - L_R)$.

As there is some possibility of sign differences for the elements of Λ, long-run estimates of uncertainty are obtained. To estimate the effects of NER uncertainty on export growth, for example, I use:

$$LongRun_{h_{NN}\to\Delta X_t} = \frac{\sum_{j=1}^{12}\lambda^{(j)}_{X,h_{NN}}}{1 - \sum_{j=1}^{P}\phi^{X,X}_j}(\sigma_{h_{N,N}})^{1/2}, \tag{4.7}$$

where $\phi^{X,X}_j$ denotes the coefficient on the *j*-th lag of export growth in the export growth equation, and where $\sigma^{1/2}_{h_{N,N}}$, denotes the unconditional standard-deviation of measured nominal exchange rate uncertainty.

5. Main results

This section provides several sets of results, related to the effects of both RER and NER uncertainty on bilateral Chinese exports. The baseline findings for uncertainty are presented in Table 2, which contains results for the full sample from 1994 through 2017 under the assumption of RMB invoicing. For all tables, quantities on the left hand side refer to results for the three variable system where the relevant exchange rate is the RER, while results on the right replace the RER with the NER. The likelihood ratio test statistics that exchange rate uncertainty exhibits no effects on export growth are reported under the

Table 2
Effects of uncertainty on trade for the full sample: yuan invoiced exports.

Country	Test-Stat $\lambda^j_{x,h_{RR}} = 0$ RER	Long-Run $h_{RR} \rightarrow \Delta X$ RER	Long-Run $\Delta R \rightarrow \Delta X$ RER	Test-Stat $\lambda^j_{x,h_{NN}} = 0$ NER	Long-Run $h_{NN} \rightarrow \Delta X$ NER	Long-Run $\Delta N \rightarrow \Delta X$ NER
Germany	37.9056*** [0.0002]	**−0.0040**	−0.0043	30.9466*** [0.0020]	**−0.0040**	−0.0022
Hong Kong	31.4258*** [0.0017]	**−0.0028**	0.0023	24.2818** [0.0186]	**−0.0066**	−0.0018
India	21.5950** [0.0423]	**−0.0118**	−0.0111	18.6147* [0.0983]	**−0.0096**	−0.0077
Japan	11.8911 [0.4545]	0.0054	0.0001	27.9898*** [0.0056]	**0.0004**	−0.0028
Korea	27.8847*** [0.0058]	**−0.0113**	−0.0085	25.1565** [0.0141]	**−0.0101**	−0.0112
Netherlands	46.2450*** [0.0000]	**−0.0038**	−0.0018	49.6473*** [0.0000]	**−0.0030**	−0.0011
Singapore	17.1626 [0.1436]	−0.0004	−0.0075	13.5832 [0.3281]	0.0031	−0.0137
United Kingdom	49.4234*** [0.0000]	**−0.0020**	−0.0032	47.7110*** [0.0000]	**−0.0021**	−0.0018
United States	15.0799 [0.2371]	0.0036	−0.0068	10.2321 [0.5936]	−0.0036	−0.0063
Vietnam	11.8773 [0.4556]	0.0024	0.0145	18.9012 * [0.0909]	**−0.0054**	0.0115

*, **, *** Denote rejection of the null hypothesis at the 10%, 5%, and 1% levels, respectively.
Notes: Results under $\lambda^j_{x,h_{RR}} = 0$ ($\lambda^j_{x,h_{NN}} = 0$) provide test-statistics and p-values (in brackets) for the null that all coefficients on the lagged conditional standard deviations for the real exchange rate (nominal exchange rate) are jointly zero in the export growth equations. Values in bold-font indicate significance based on a 10% test-size. $h_{RR} \rightarrow \Delta X$ refers to the estimated long run effect on export growth of a one standard deviation increase in the conditional standard deviation of the residuals of the RER (with similar meaning for $h_{NN} \rightarrow \Delta X$ as it relates to the nominal exchange rate). $\Delta R \rightarrow \Delta X$ and $\Delta N \rightarrow \Delta X$ refer to the estimated long run effects of the growth of the RER and NER on export growth.
The specific export equation for Korea is reported below.

$$\Delta X_t = \mathbf{0.05} - \mathbf{0.71}\Delta X_{t-1} + \mathbf{0.33}\Delta Y^*_{t-1} - \mathbf{0.39}\Delta R_{t-1} - \mathbf{0.32}\Delta X_{t-2} + \mathbf{0.41}\Delta Y^*_{t-2} - 0.06\Delta R_{t-2} - 0.47h^{1/2}_{RR,t-1} - \mathbf{1.39}h^{1/2}_{RR,t-2} + \mathbf{1.32}h^{1/2}_{RR,t-3}$$
$$- 0.26h^{1/2}_{RR,t-4} - 0.13h^{1/2}_{RR,t-5} - 0.30h^{1/2}_{RR,t-6} + 0.39h^{1/2}_{RR,t-7} - 0.30h^{1/2}_{RR,t-8} + 0.51h^{1/2}_{RR,t-9} - 0.18h^{1/2}_{RR,t-10} + 0.20h^{1/2}_{RR,t-11} - \mathbf{0.35}h^{1/2}_{RR,t-12} + \widehat{\epsilon_{X_t}}.$$

heading "Test-Stat." Finally, there are two sets of long run impacts that are reported, both the impact of exchange rate uncertainty, and the growth rate of the exchange rate itself, on export growth.

The findings are quite compelling. First, it is interesting to note that there is no evidence that exchange rate uncertainty impacts trade between the US and China when employing a 10% test size. In the case of the RER, the estimated insignificant effects are positive, while negative estimates are reported for the NER. The lack of evidence supporting the presumed decline in export growth for the US is a robust finding throughout this manuscript. Simply, there is little evidence supporting a negative link between Chinese export growth and uncertainty with the US, regardless of assumptions used for currency invoicing, time period used, or even whether relative prices are measured by the real or nominal exchange rate.

Ignoring the US, the results generally provide robust support for the hypothesis that uncertainty is harmful to trade. Specifically, across both exchange rates, the estimated effect is negative for the vast majority of countries, and when significant, the results show that the uncertainty-growth link is negative in an overwhelming 13 of 14 cases. Turning first to the RER results, uncertainty is never found to exhibit a positive and statistically significant impact, with statistically negative effects found for most countries. Estimated impacts for Singapore are negative and only marginally insignificant, while coefficient estimates for Vietnam and the US are positive and statistically insignificant. In terms of the estimated impacts, the results are reasonable and economically important. The findings show the overall negative effects of RER uncertainty are relatively small for Germany, the Netherlands, and the UK, where one-standard deviation increases in measured RER uncertainty cause long-run declines in export growth of 0.40%, 0.38%, and 0.20%, respectively. In contrast, the impact appears to be much more severe for exports to Korea and India, where the associated declines are larger than 1.1%.

The NER-based findings in Table 2 provide general conclusions that are very consistent with those emerging from analysis of the RER. Amongst the statistically significant results, there are 7 cases where nominal uncertainty has deleterious effects on Chinese bilateral trade, and only a single case where the effect is positive. For Japan, there is evidence that nominal volatility has a very small statistically significant positive impact. For Vietnam, we now find that a one-standard deviation increase in nominal uncertainty significantly lowers long-run export growth by 0.54%. For Germany, Hong Kong, India, the Netherlands, and the UK, results continue to indicate volatility will decrease imports for China. Further, for these countries, the quantified effects of nominal risk are generally quite similar to the RER counterparts, and we again conclude the uncertainty is especially damaging for export growth to India and Korea.[9]

For each country, at least 36 parameters are estimated within the system, such that it is not feasible to present the full set of parameters.[10] Some general comments are nonetheless in order. Across all

[9] The results for the long-run effects of the exchange rate itself on export growth are also reported in Table 2. The results provide the expected finding that nominal yuan strength is harmful to export growth. For example, a 0.63% decline in export growth follows a one standard deviation increase in the growth of the USD price of the RMB.

[10] All GARCH equations meet the non-negativity constraints for κ_i, α_i, and δ_i, and stationarity constraints, $\alpha_i + \delta_i + 0.50\lambda_i < 1$ (see, for example Ling and McAleer, 2002). As emphasized below, there may be specific interest in λ_i, where, for the NER, $\widehat{\lambda_N}$ is equal to −0.203, 0.088, 0.060, 0.496, −0.670, −0.268, −0.396, and −0.204 for Germany, Hong Kong, India, Japan, Korea, the Netherlands, Singapore, and the UK.

Table 3
Effects of uncertainty on trade for the full sample: foreign currency invoiced exports.

Country	Test-Stat $\lambda^j_{x,h_{RR}} = 0$ RER	Long-Run $h_{RR} \rightarrow \Delta X$ RER	Long-Run $\Delta R \rightarrow \Delta X$ RER	Test-Stat $\lambda^j_{x,h_{NN}} = 0$ NER	Long-Run $h_{NN} \rightarrow \Delta X$ NER	Long-Run $\Delta N \rightarrow \Delta X$ NER
Germany	22.89698** [0.0286]	**−0.0047**	0.0039	12.42182 [0.4124]	−0.0034	0.0084
Hong Kong	31.1789*** [0.0018]	**−0.0017**	0.0032	24.6120** [0.0168]	**−0.0075**	0.0010
India	21.3283** [0.0458]	**−0.0087**	−0.0022	19.6041* [0.0750]	**−0.0088**	0.0009
Japan	31.3546 *** [0.0017]	**−0.0006**	0.0117	67.3317*** [0.0000]	**−0.0034**	0.0110
Korea	36.4130*** [0.0003]	**−0.0110**	0.0131	35.3093*** [0.0004]	**−0.0111**	0.0102
Netherlands	14.2112 [0.2874]	−0.0074	0.0033	14.6800 [0.2594]	−0.0068	0.0050
Singapore	16.3272 [0.1767]	−0.0012	−0.0005	13.8542 [0.3101]	0.0027	−0.0059
United Kingdom	19.0780* [0.0867]	**−0.0017**	0.0015	17.6416 [0.1270]	−0.0016	0.0033
United States	8.5018 [0.7448]	−0.0011	−0.0033	15.1760 [0.2320]	−0.0032	−0.0028
Vietnam	11.7765 [0.4638]	0.0060	0.0150	16.3301 [0.1766]	−0.0043	0.0143

*, **, *** Denote rejection of the null hypothesis at the 10%, 5%, and 1% levels, respectively.
Notes: Results under $\lambda^j_{x,h_{RR}} = 0$ ($\lambda^j_{x,h_{NN}} = 0$) provide test-statistics and p-values (in brackets) for the null that all coefficients on the lagged conditional standard deviations for the real exchange rate (nominal exchange rate) are jointly zero in the export growth equations. Values in bold-font indicate significance based on a 10% test-size.
Here, $h_{RR} \rightarrow \Delta X$ refers to the estimated long run effect on export growth of a one standard deviation increase in the conditional standard deviation of the residuals of the real exchange rate (with similar meaning for $h_{NN} \rightarrow \Delta X$ as it relates to the nominal exchange rate). $\Delta R \rightarrow \Delta X$ and $\Delta N \rightarrow \Delta X$ refer to the estimated long run effects of the growth of the real exchange rate and nominal exchange rate on export growth.

specifications for exports, the vast majority of estimated coefficients on lagged uncertainty terms are negative, with the majority of those that are significant also being negative. Consider, for example, the export growth equation for the Korean RER depicted in Table 2, with bold quantities denoting statistical significance with a 10% test size.[11] As seen in the equation, there are several individual parameters that are statistically significant, including the negative coefficient at lag 12. This demonstrates the importance of considering lagged effects of up to one year. To summarize remaining results, the Korean equation is somewhat representative of other specifications. In general, the first two lagged coefficients are large and negative, and there are usually significant coefficients for at least one higher order lagged value.

As a robustness check to the baseline results, Table 3 contains findings where exports have been converted into the currency of the listed country. Arguably, the most important result under the assumption of foreign currency invoicing is the continued robust finding of a negative link between uncertainty and trade. There are only 2 instances across both measures of the exchange rates where estimated effects are positive, and in no case are these effects statistically significant. Secondly, we notice the continued stubborn lack of evidence that uncertainty deters Chinese-US trade, where estimated long run effects are again insignificant in both equations. There are 6 countries where RER uncertainty exhibits a statistically negative impact, and the estimated effects are negative for every country but Vietnam. For nominal uncertainty, the estimated impact is negative for every country except Singapore, and there are now 4 countries with a statistically significant negative link. Finally, it is interesting to note that there is now evidence that Japanese trade is negatively impacted by both NER and RER uncertainty.

Finally, we turn to the findings in Table 4, which contain results under the assumption of RMB invoicing for the subsample from 2005 to 2017. Of course, for the algorithm employed here, cutting the sample in half results in less precise parameter estimates, and to insure convergence, the number of lags was decreased from 12 to 8. The subsample results generally confirm the findings from Tables 2 and 3, where the estimated impact of uncertainty is negative for most countries, especially when significant, and where little evidence is presented that Chinese trade is harmed by uncertainty with the US. For the only time in this paper, however, there is evidence of a significant link for the US, in this case based on a 10% test for the NER equation. Even still, the long run impact in this case is shockingly small; a one-standard deviation increase in measured uncertainty would cause export growth to decline by a paltry 0.08%.

In totality, the results are surprisingly robust, especially when considering the complicated algorithm employed here. For Germany, Hong Kong, India, Korea, and the Netherlands, there is ubiquitous evidence across all specifications supporting the assertion that uncertainty exhibits negative effects on export growth, with statistically significant links in most cases. Additionally, for the full sample, and across both Tables 2 and 3, if we include the marginally insignificant results for the RER of Singapore, negative linkages are uncovered for every country except the US. Given evidence of possible trade deterring of uncertainty, we next consider preliminary investigation of the potential factors affecting RMB risk.

6. Analysis of Chinese exchange rate uncertainty

The techniques studied here likely yield an important methodological contribution and can also be used to provide an understanding

[11] With $l_t(\hat{\theta})$ denoting the likelihood function for the t-th observation evaluated at $\hat{\theta}$, the standard errors are calculated using the outer-product of the score function. Specifically, the information matrix uses numerical derivatives as $I(\hat{\theta}) = T^{-1}\sum_{t=1}^{T}[\frac{\partial l_t}{\partial \hat{\theta}}][\frac{\partial l_t}{\partial \hat{\theta}}]'$. The standard errors can be calculated using the diagonal elements of the matrix given by $T^{-1}I(\hat{\theta})^{-1}$.

Table 4
Effects of uncertainty for restricted sample: Sample 2005-2017.

Country	Test-Stat $\lambda^j_{x,h_{RR}} = 0$ RER	Long-Run $h_{RR} \to \Delta X$ RER	Long-Run $\Delta R \to \Delta X$ RER	Test-Stat $\lambda^j_{x,h_{NN}} = 0$ NER	Long-Run $h_{NN} \to \Delta X$ NER	Long-Run $\Delta N \to \Delta X$ NER
Germany	8.3490 [0.4001]	−0.0074	−0.0089	9.1927 [0.3263]	−0.0065	−0.0062
Hong Kong	32.2697*** [0.0000]	**−0.0059**	−0.0019	23.7854 *** [0.0025]	**−0.0143**	−0.0063
India	14.4908* [0.0698]	**−0.0054**	−0.0144	15.5359** [0.0495]	**−0.0120**	−0.0100
Japan	40.0582*** [0.0000]	**−0.0131**	0.0019	18.9197** [0.0153]	**0.0055**	0.0012
Korea	26.9513*** [0.0007]	**−0.0094**	−0.0110	21.2603*** [0.0065]	**−0.0088**	−0.0087
Netherlands	20.1678*** [0.0097]	**−0.0047**	−0.0038	19.8211** [0.0110]	**−0.0058**	−0.0033
Singapore	11.3146 [0.1845]	0.0155	−0.0160	9.4012 [0.3096]	0.0163	−0.0216
United Kingdom	10.5875 [0.2262]	0.0001	−0.0098	14.6385* [0.0666]	**0.0010**	−0.0068
United States	4.4693 [0.8125]	−0.0015	−0.0059	15.4228 * [0.0514]	**−0.0008**	−0.0080
Vietnam	13.2219 [0.1044]	0.0085	0.0086	12.1620 [0.1441]	0.0134	−0.0029

*, **, *** Denote rejection of the null hypothesis at the 10%, 5%, and 1% levels, respectively.
Notes: Results under $\lambda^j_{x,h_{RR}} = 0$ ($\lambda^j_{x,h_{NN}} = 0$) provide test-statistics and p-values (in brackets) for the null that all coefficients on the lagged conditional standard deviations for the real exchange rate (nominal exchange rate) are jointly zero in the export growth equations. Values in bold-font indicate significance based on a 10% test-size.
Here, $h_{RR} \to \Delta X$ refers to the estimated long run effect on export growth of a one standard deviation increase in the conditional standard deviation of the residuals of the real exchange rate (with similar meaning for $h_{NN} \to \Delta X$ as it relates to the nominal exchange rate). $\Delta R \to \Delta X$ and $\Delta N \to \Delta X$ refer to the estimated long run effects of the growth of the real exchange rate and nominal exchange rate on export growth.

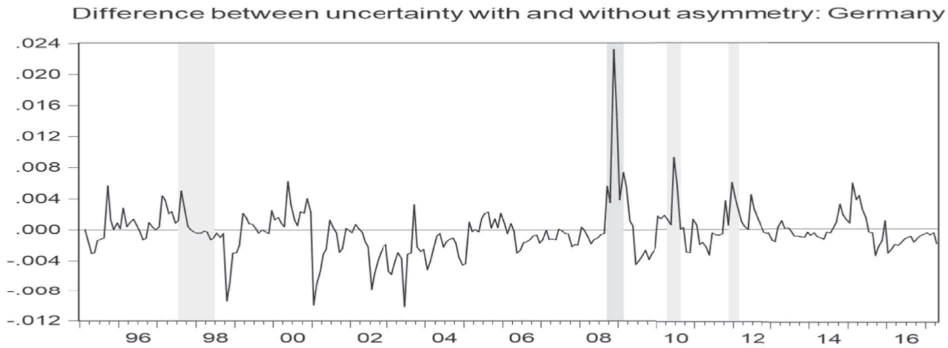
related to the evolution and causes of exchange rate uncertainty in China. The estimation routine yields a time varying conditional covariance matrix and individual specifications for each trading partner's conditional variances for all variables, including the relevant exchange rate. The last feature, in particular, can be leveraged to study the impacts of asymmetry and relevant macroeconomic variables on measured exchange rate uncertainty.

Based on the estimated models above, the unconditional correlation coefficients, $\widehat{\rho_{h^{1/2}_{RR},h^{1/2}_{NN}}}$, between the measure of real and nominal uncertainty for each country exceed 75% for all countries except Hong Kong and the United States. Both China and Hong Kong pegged their currencies to the US dollar during our sample, such that shocks to relative prices generate differences between measured uncertainty for these two country pairs. For the remaining countries, the correlation coefficient is typically glaringly high, exceeding 97% for Germany, India, Korea, the Netherlands, and the UK. As a result, in what follows below, the discussion centers on measured nominal uncertainty.

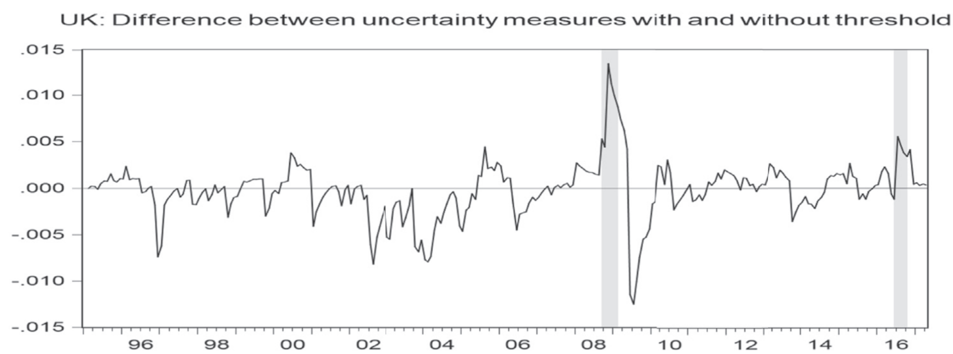
In analyzing nominal uncertainty for China, the estimated time varying conditional covariance matrix, $\widehat{H}_t$, provides evidence supporting both the importance of asymmetric effects, while also highlighting the need for multivariate methods. Referring to the results in section 5, τ_N was statistically significant for 8 countries. For Japan, $\widehat{\tau_N} = 0.496$, implying unexpected yen appreciations increase nominal uncertainty more than associated depreciations, perhaps owing to the Bank of Japan's historical problems with a strong yen. Small positive coefficients for Hong Kong and India suggest there is a modest difference between the effects of appreciations and depreciations. For the remaining countries, as discussed above, $\widehat{\tau_N}$ ranges from −0.203 to −0.670. Consider Fig. 1, which displays the difference between the estimated measure of uncertainty with asymmetric effects versus the same quantity without for Germany, the UK, and Korea. These figures show the amplified effects of unexpected RMB strength. The highlighted areas for Germany demonstrate differential impacts during the Asian currency crisis, the collapse of Lehman Brothers, and for two periods in 2010 and 2011, associated with the European debt crisis. During the collapse of Lehman Brothers, in particular, the unexpected declines in the euro, pound, and to a lesser extent, the won, result in a higher level of measured uncertainty than would be achieved without the allowance of asymmetry. To the extent exchange rate uncertainty is harmful, these findings support Chinese decisions in the past to telegraph moves aimed at gradual RMB appreciation so as to avoid sudden and unexpected currency gains.

Fig. 2 displays the conditional covariance between exchange rate and export growth residuals as calculated from the system above. As expected, contemporaneous shocks to the exchange rate are nearly always negatively related to export growth disturbances, implying unexpected RMB strength is associated with unexpected declines in trade. The strength of the relationship varies across the sample. For the US and Hong Kong, the negative relationship appears to have strengthened since the end of the dollar peg in 2005, implying a stronger link between the exchange rate and export growth. In several instances, including for Germany, Korea, and the Netherlands, there is evidence that the negative covariance strengthens following events such as the Asian currency crisis and the collapse of Lehman Brothers.

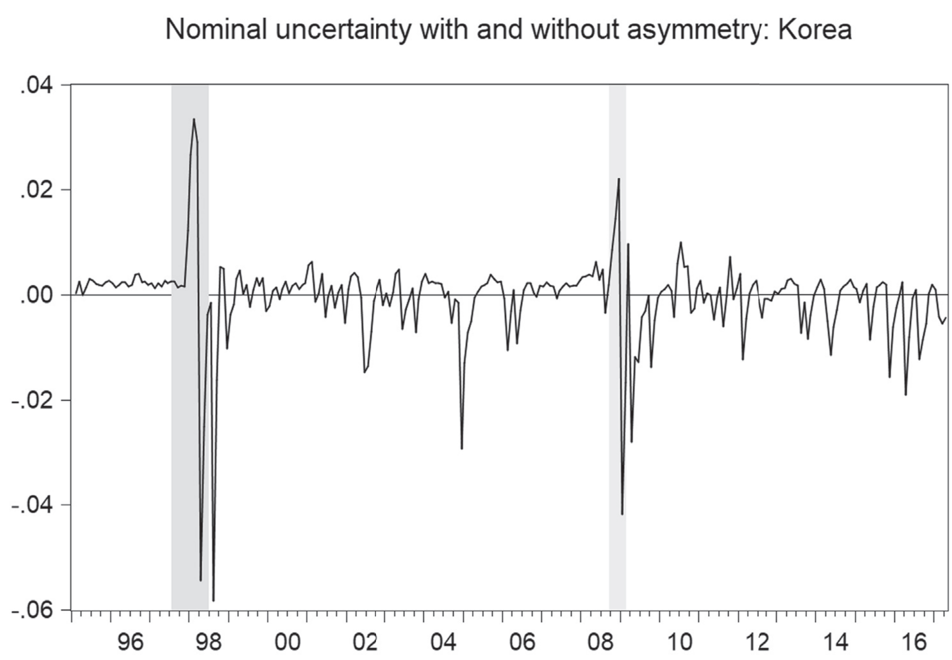
Fig. 3 depicts the estimated values of NER uncertainty, revealing several characteristics regarding its evolution. The graphs highlight time periods associated with several economic events, including (i) the Asian currency crisis, (ii) the collapse of Lehman Brothers at the height of the financial crisis in 2008, (iii)-(iv) two time periods associated with the debt crisis in Europe, and (v) the move by the PBOC in August 2015 to redefine the mechanism used to determine the daily parity rate



(a)

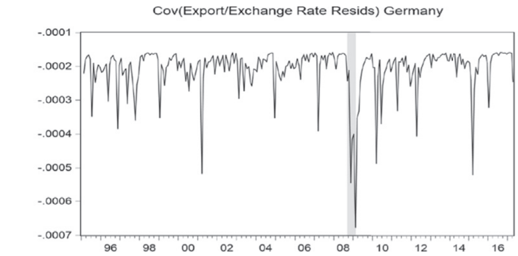


(b)

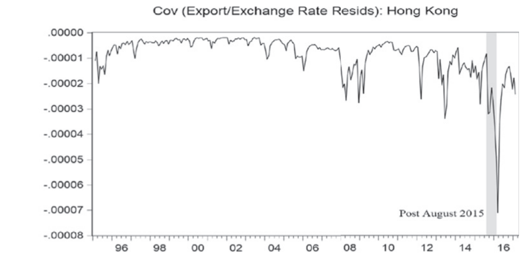


(c)

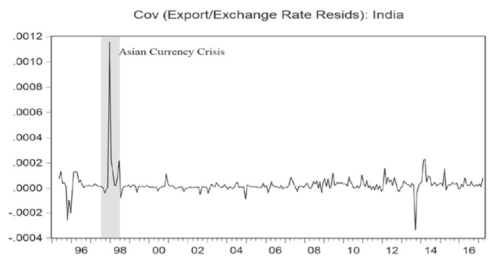
Fig. 1. (a) Difference between nominal uncertainty with and without asymmetry: Germany (b) Difference between nominal uncertainty with and without asymmetry: United Kingdom (c) Difference between nominal uncertainty with and without asymmetry: Korea.



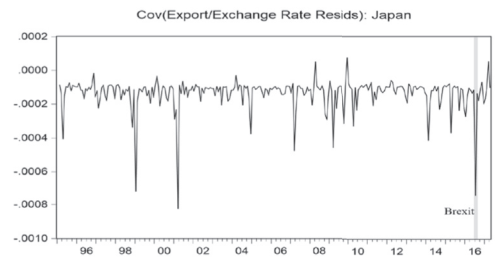
(a) Germany: $h_{X,N}$



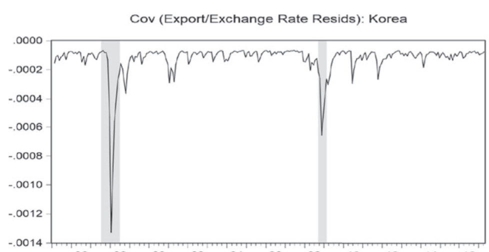
(b) Hong Kong: $h_{X,N}$



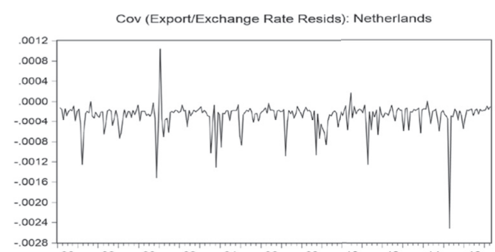
(c) India: $h_{X,N}$



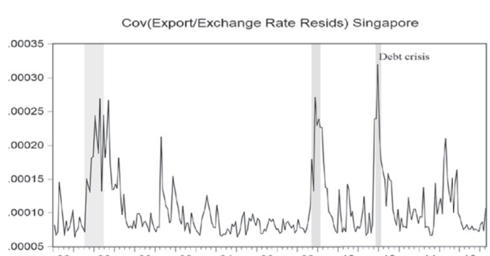
(d) Japan: $h_{X,N}$



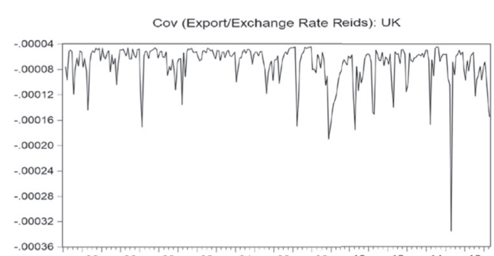
(e) Korea: $h_{X,N}$



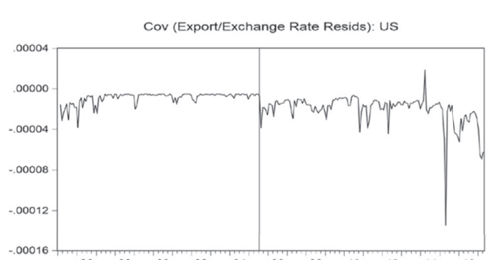
(f) Netherlands: $h_{X,N}$



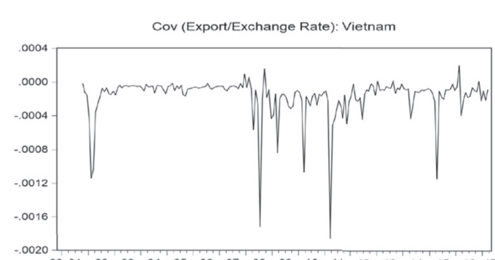
(g) Singapore: $h_{X,N}$



(h) UK: $h_{X,N}$

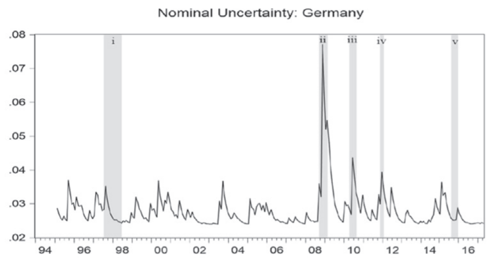


(i) US: $h_{X,N}$

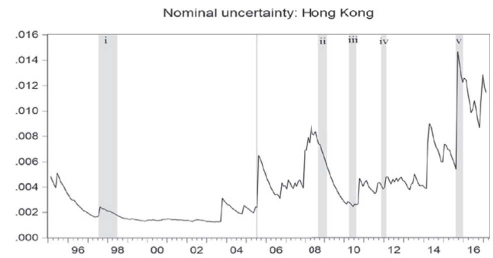


(j) Vietnam: $h_{X,N}$

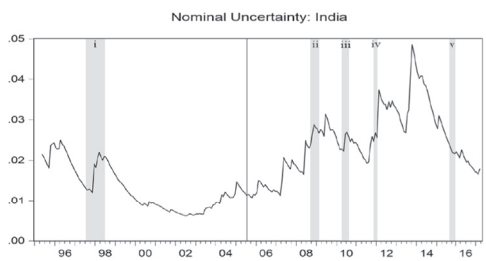
Fig. 2. Conditional covariance between exchange rate and export growth disturbances.



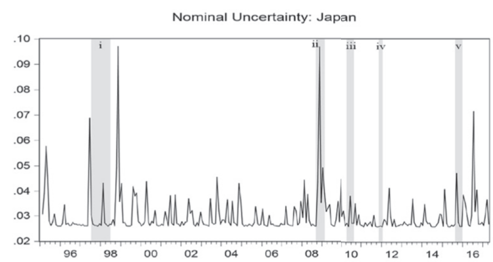
(a) Nominal Uncertainty: Germany



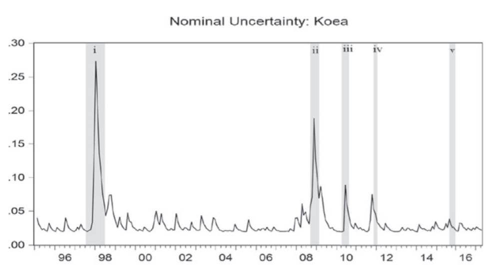
(b) Nominal Uncertainty: Hong Kong



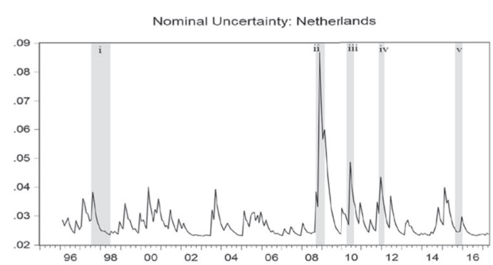
(c) Nominal Uncertainty: India



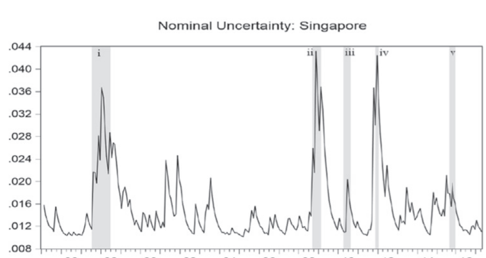
(d) Nominal Uncertainty: Japan



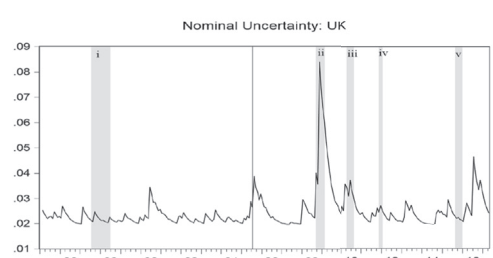
(e) Nominal Uncertainty: Korea



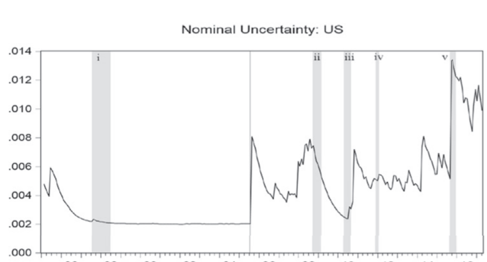
(f) Nominal Uncertainty: Netherlands



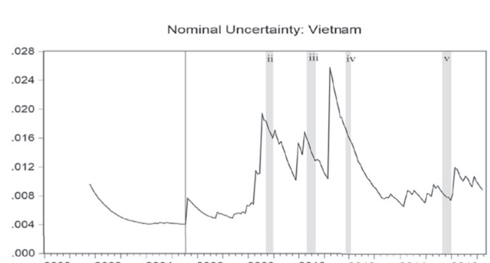
(g) Nominal Uncertainty: Singapore



(h) Nominal Uncertainty: UK



(i) Nominal Uncertainty: US



(j) Nominal Uncertainty: Vietnam

Fig. 3. Nominal exchange rate uncertainty.

Table 5
Impact of macroeconomic variables on NER uncertainty.[a]

Variable:	$i_t - i_t^F$	π_t^{China}	π_t^F	$Grow_t^{China}$	$Grow_t^F$	Break/*Policy*
Germany: Model 1	−0.2967	−0.0087	**2.0778** **	N/A	N/A	**3.5035***
Germany: Full Model	**−4.9584** ***	**2.9818** ***	**−2.2775** **	**3.5482***	**−3.6387***	**3.1482** ***
Hong Kong: Model 1	**7.7288***	**7.4346***	**4.9078** ***	N/A	N/A	−0.9032
Hong Kong: Full Model	**2.3480** **	**4.3426***	**2.1939** **	0.0830	0.0871	**−3.9514***
India: Model 1	**191.9755***	**89.1480** ***	**164.0418***	N/A	N/A	**−59.7773***
India: Full Model	**133.43***	**92.810** ***	**6.2804***	**−7.6331***	**113.09***	**36.974***
Japan: Model 1	−0.3835	**−1.6620** *	1.3482	N/A	N/A	**−2.5003** **
Japan: Full Model	**5.4054***	**−2.0702** **	**−11.070***	**−7.0463***	1.0754	**7.3923***
Korea: Model 1	**1.6533** *	**3.9346***	1.1113	N/A	N/A	1.3248
Korea: Full Model	0.7876	0.9991	1.2741	0.1449	0.7377	1.6431
Netherlands: Model 1	−0.8357	1.3347	**1.8726** *	N/A	N/A	**2.7519***
Netherlands: Full	**−1.8811** *	**4.5968** ***	1.6102	**1.7876** *	**−3.7606***	0.6637
Singapore: Model 1	0.1127	0.0911	**2.6029***	N/A	N/A	0.1080
Singapore: Full Model	0.3612	−0.2962	**3.2500***	−0.1763	−0.6272	**2.4650** **
UK: Model 1	−0.5505	**2.7299***	−1.0149	N/A	N/A	0.2652
UK: Full Model	**−3.4004***	−0.5233	0.3170	**5.7469***	**−2.8219***	**4.4421***
United States: Model 1	**6.9365***	**8.5966***	**−6.5855***	N/A	N/A	**−10.1509***
United States: Full Model	0.6901	−0.0648	−0.0059	0.3725	**7.1872***	**−25.7561***
Vietnam: Model 1	−0.8205	**7.0906***	**138.4753** ***	N/A	N/A	**−35.9418***
Vietnam: Full Model	−0.5355	−1.4143	**7.3626** ***	**−4.4248** ***	−1.3537	−1.2080

*, **, *** Denote rejection of the null hypothesis at the 10%, 5%, and 1% levels, respectively. Notes: The table provides t-statistics where standard errors have been calculated using the outer product of the gradient of the likelihood function as documented in the text. The conditional variance of model 1 is specified as

$$h_{NN,t} = \kappa_N + \alpha_N u_{N,t-1}^2 + \delta_N h_{NN,t-1} + \tau_N I_{\{u_{N,t-1}<0\}} u_{N,t-1}^2 + \eta_1 (i_t - i_t^*) + \eta_2 \pi_t + \eta_3 \pi_t^F + \eta_4 PEG_t,$$

where PEG_t takes on the value zero except during the time period from 1994 to 2005 when the yuan was pegged to the dollar. The full model replaces PEG_t with the policy uncertainty variable studied in Baker et al. (2016) and adds the proxies for income growth in China ($Grow_t^{China}$) and China's foreign trading partner ($Grow_t^F$).

[a] Inflation rates from China and their trading partner (π_t, π_t^F), are calculated as the log year over year change in the CPI from the text. To proxy monetary policy differences, I use the refinance rate collected from the State Bank of Vietnam and the discount rate from the Bank of Japan. For the remaining countries, central bank policy interest rate differentials, $i_t - i_t^F$, are obtained using data from the BIS (https://www.bis.org/statistics/cbpol.htm). To proxy output growth in China, $Grow_t^{China}$, year over year log changes in retail trade sales from the OECD is obtained, given the difficulty in obtaining industrial production data due to irregularities around the Chinese New Year. For the remaining countries, growth is calculated as log year over year changes in the available industrial production data.

against the USD.[12] First, we observe that measured risk has markedly increased in Hong Kong, India, Vietnam, and the US following the decision by the PBOC to end the tight dollar peg in July 2005. For Hong Kong and to a lesser extent, Vietnam, who have a history of pegging to the US dollar, exchange rate uncertainty has mimicked the US experience. At the same time, pegging has not inoculated China from increases in uncertainty for other trading partners whose currencies can be quite volatile against the dollar. Most notably, there are large increases in uncertainty for nearly every country in the time period immediately after the collapse of Lehman Brothers in September 2008. Uncertainty also increased for the yuan against several currencies in different combinations following the Asian currency crisis, the emergence of the debt crisis in Europe, and Brexit, with results that are only slightly muted for India. The results hint that RMB uncertainty against other currencies increased as China minimized movements against a volatile dollar, which, in turn, was being affected by shocks outside of the control of policy makers in China.

Although the anecdotal evidence shows that Chinese exchange rate uncertainty may be driven largely by exogenous events, the methodology in this paper can be used to study the impact of important macroeconomic variables on uncertainty, where all model parameters are again estimated simultaneously. To this end, the exchange rate volatility equation in (4.4) was amended to include NH_N macroeconomic variables, $z_{t,j}$, lagged ℓ time periods as follows,

$$h_{NN,t} = \kappa_i + \alpha_i u_{N,t-1}^2 + \delta_i h_{NN,t-1} + \tau_i I_{\{u_{N,t-1}<0\}} u_{N,t-1}^2 + \sum_{j=1}^{NH_N} \eta_j z_{j,t-\ell}. \tag{6.1}$$

In terms of precedence for the selection of relevant variables, $z_{j,t}$, the existing literature on the causes of exchange rate volatility, especially for China, is relatively scant. As an exception, Grossmann et al. (2014) estimate a panel VAR for several economies including China and provide an impressive survey related to the anticipated effects of several variables, including inflation rates, industrial production growth, and monetary variables. Inflation differentials, in particular, are found to be an important source of overall volatility. Based on their review of theory and analysis, a number of variables are added to equation (6.1), including monetary policy-based interest rate differentials, inflation rates, and measures of economic output in both China and their relevant trading partner.[13] Additionally, I consider the implications of China's decision to end the dollar peg using a dummy variable that takes on the value one until June 2005 and zero after. Finally, I use the uncertainty variable from Baker et al. (2016), who calculates general policy uncertainty using data collected from newspapers in China and other countries.[14] Economically, as discussed in Grossmann et al. (2014), domestic growth may be expected to have a negative impact, as growth calms exchange rate markets. Increases in the interest rate gap might ordinarily lead

[12] The first time period associated with the debt crisis, where significant social unrest accompanied the IMF sponsored bailout of Greece, also covers the flash crash on May 6, 2010. The second time period, at the end of 2011, follows the expansion of the crisis into Ireland, Italy, Portugal, and Spain and a proposed referendum against austerity in Greece.

[13] For additional discussion, see Ganguly and Breuer (2010) who also provide insight on both NER and RER volatility.

[14] Data availability substantially decreases the effective sample for every trading partner, especially for eurozone economies, where interest rate data is only available after 1999. Additional detail on data can be found in the notes to Table 5.

to volatility in open capital markets. Here, however, relative tightening for China could be used to smooth currency outflows and might be expected to decrease currency risk, especially against developed trading partners. The remaining variables are likely positively related to uncertainty, where, for example, increases in inflation could be distortionary and could also signal possible bubbles.

Table 5 contains the findings for tests that the relevant variables have no impact on nominal uncertainty from two specifications with $\ell = 0$. In the first, interest rate differentials, inflation rates, and the break dummy variable are included. The second model, labelled "Full", adds relevant growth variables and replaces the dummy variable with policy uncertainty. Preliminary estimation with the policy uncertainty variable and the peg dummy revealed that the inclusion of both was likely unnecessary, with at least one generally testing out as insignificant. Given the potential dominance of exogenous events as discussed above, it is perhaps not surprising that there are a large number of statistically insignificant coefficients.[15] Of note, however, there does appear to be compelling evidence that Chinese inflation tends to increase exchange rate uncertainty. For the first model, there are 6 cases where inflation significantly increases uncertainty and only one (for Japan) where uncertainty decreases. Of note, the effects are positive for Hong Kong, India, Korea, the UK, and Vietnam, where earlier evidence showed trade deterring effects of uncertainty. The results of the full model may be seen as slightly weaker, although there is still evidence of positive statistical significance for four countries where NER volatility significantly lowered export growth as found in Table 2. Interestingly, the impact of the inflation rate of China's developing trading partners is unambiguously positive, and always significant except in the case of Korea. Additionally, for these economies, except Vietnam, it is found that uncertainty increases as interest rate differentials grow. These findings suggest that as Chinese monetary policy becomes relatively tight compared to these countries, exchange rates become more volatile. The opposite conclusion is reached for the full model for Germany, the Netherlands, and the UK, suggesting that relatively loose monetary policy in China is associated with increased volatility.

Turning to the effects of economic activity, for India, Japan, and Vietnam, increases in Chinese growth are associated with declines in volatility, perhaps suggesting that for these trading partners in Asia, a robust Chinese economy reduces volatility. Otherwise, perhaps matching the findings of Grossmann et al. (2014), there is no consensus regarding the effects of economic activity, either in China or abroad, with estimated effects that are insignificant in most remaining specifications.

Finally, it is interesting to note that policy uncertainty is negatively associated with exchange rate uncertainty for Hong Kong, the US, and Vietnam, where results are statistically significant for the first two countries. These results seem to suggest that as various type of policy uncertainty arise, the PBOC is able to smooth the exchange rate in response. The US-dollar pegs of Vietnam and especially Hong Kong ensure that this smoothing is passed on to the Hong Kong dollar and dong. Otherwise, policy uncertainty in China is positively related to exchange rate uncertainty, with effects that are typically statistically significant. The results in this section seem to highlight that although many exogenous factors may have contributed to exchange rate volatility, Chinese inflation and general policy uncertainty may have impacted uncertainty for many economies where evidence of a negative trade link was established.

[15] As a by-product of these estimates, we obtain an additional robustness check for the findings in Tables 2–4. Broadly speaking, the results, which are available upon request, are very supportive of the general findings. For the restricted sample after 1999, there is some evidence that nominal uncertainty increases export growth for the two eurozone countries. For most remaining countries, except the US, there is again robust evidence that nominal uncertainty reduces export growth.

7. Conclusion

This article investigates the behavior of the world's largest exporter and her most important trading partners in an environment of increasing exchange rate uncertainty. The analysis is conducted over a time span that has seen the yuan move from being tightly controlled and unused outside of China to an international currency whose movements are more market driven. The use of a very general methodology against this backdrop produces findings that can aid researchers and policy makers that wish to understand potential causes of yuan risk and its anticipated impacts on different trading partners. Additionally, the results may have implications for other large emerging economies, especially those considering changes in exchange rate policy, while the methods may offer contributions to those studying uncertainty effects for other macroeconomic variables in a more general setting.

Here, the effects of uncertainty on trade are estimated using a multivariate system for exports, foreign income, and both a real and nominal exchange rate based on the DCC-GARCH model of Engle (2002), where all model parameters are estimated simultaneously. The multivariate methods allow for time varying conditional covariances for the innovations in the system and idiosyncratic modeling choices for the individual conditional variances. This permits the allowance of asymmetry in the response of exchange rate uncertainty to positive and negative shocks and ultimately to the inclusion of relevant macroeconomic variables as potential causes of volatility. Additionally, the model employed here allows uncertainty to impact export growth for a full year, an innovation that proves important in the current context. To summarize the results, there is substantial evidence of a negative connection between trade and exchange rate volatility for almost every country in the sample, with effects that appear to be amplified for India and Korea. Interestingly, there is virtually no robust evidence across the numerous specifications that suggest export growth to the US is negatively impacted when exchange rates are uncertain.

Evidence from the individual measures of uncertainty are presented and demonstrate that very sensible attempts to stabilize the yuan-US dollar relationship may have come at the cost of increased volatility for countries like the UK, where the evidence suggests uncertainty can exhibit negative impacts. Further evidence regarding the evolution of China's exchange rate volatility reveals that although exogenous events could possibly dominate, Chinese inflation may have contributed to currency risk, particularly for the economies where trade was negatively affected.

The findings in this paper strongly suggest that exchange rate risk may have differential impacts depending on the trading partner being investigated, where specifically, there is virtually no evidence that export growth to the United States is impacted by uncertainty. The natural question that arises is why, during certain times, are some countries able to avoid the negative consequences of exchange rate uncertainty that seem to affect other countries and/or their trading partners? For China, internationalization of the yuan and increasing availability of hedging instruments may allow traders to minimize risk for certain trading partners. Additionally, the rising use of trade finance may provide an opportunity for exporters to avoid risk and expand export activities with certain countries. In this vein, it may be worth studying the environment under which Chinese companies can find protection and external financing when establishing trade with different countries. Of note, Hericourt and Poncet (2013) provide evidence for Chinese firms that financial development is important in mitigating the negative impact of exchange rate uncertainty for companies heavily reliant on external finance.[16] This suggests that if access to external finance becomes

[16] Recent studies have shown that export activities are intimately linked to access to external credit, including trade credit. For example, Manova et al. (2015) show the foreign affiliates and joint ventures export more in financially vulnerable industries in China, relative to their private domestic peers, with amplified effects for destination markets with high costs.

more strained for certain trading partners, exchange rate volatility will likely cause exporters to alter export decisions accordingly. If different firms with varying financing needs export to different markets, then it is plausible that exchange rate volatility should exert a varying impact on trading decisions. It seems additional analysis is merited so as to fully understand the financial and economic environment under which the potential negative consequences of uncertainty can be avoided.

Declarations of interest

None.

References

Asteriou, Dimitrios, Masatci, Kaan, Keith, Pilbeam, 2016. Exchange rate volatility and international trade: international evidence from MINT countries. Econ. Modell. 58, 133–140.

Baak, SaangJoon, 2008. The bilateral real exchange rates and trade between China and the US. China Econ. Rev. 19, 117–127.

Bacchetta, Philippe, van Wincoop, Eric, 2000. Does exchange rate stability increase trade and welfare? Am. Econ. Rev. 90, 1093–1109.

Baker, Scott, Bloom, Nicholas, Davis, Steven, 2016. Measuring economic policy uncertainty. Q. J. Econ. 131, 1593–1636.

Baum, Christopher, Caglayan, Mustafa, 2010. On the sensitivity of the volume and volatility of bilateral trade flows to exchange rate uncertainty. J. Int. Money Finance 29, 79–93.

Caglayan, Mustafa, Omar, Dahi, Demir, Firat, 2013. Trade flows, exchange rate uncertainty and financial depth: evidence from 28 emerging countries. South. Econ. J. 79, 905–927.

Cavaliere, Giuseppe, Anders, Rahbek, Robert Taylor, A.M., 2010. Cointegration rank testing under conditional heteroskedasticity. Econom. Theor. 26, 1719–1760.

Chit, Myint Moe, Rizov, Marian, Willenbockel, Dirk, 2010. Exchange rate volatility and exports: new evidence from the emerging East Asian economies. World Econ. 33, 239–263.

Chou, W.L., 2000. Exchange rate variability and China's exports. J. Comp. Econ. 28, 61–79.

Clark, John, 2017. China's evolving managed float: an exploration of the roles of the fix and broad dollar movements in explaining daily exchange rate changes. Federal Reserve Bank of New York Staff Papers 828, 1–28.

DeGrauwe, Paul, 1988. Exchange rate variability and the slowdown in growth in international trade. Int. Monet. Fund Staff Pap. 35, 63–84.

Duchesne, Pierre, Lalancette, Simon, 2003. On testing for multivariate ARCH effects in vector time series models. Can. J. Stat. 31, 275–292.

Engle, Robert, 2002. Dynamic conditional correlation: a simple class of multivariate generalized autoregressive conditional heteroskedasticity models. J. Bus. Econ. Stat. 20, 339–350.

Ethier, Wilfred, 1973. International trade and the forward exchange market. Am. Econ. Rev. 63, 494–503.

Fang, WenShwo, Lai, YiHao, Miller, Stephen, 2009. Does exchange rate risk affect exports asymmetrically? Asian evidence. J. Int. Money Finance 28, 215–239.

Francq, Christian, Zakoian, Jean-Michel, 2012. Strict stationarity testing and estimation of explosive and stationary autoregressive conditional heteroscedasticity model. Econometrica 80, 821–861.

Ganguly, Srideep, Breuer, Janice Boucher, 2010. Nominal exchange rate volatility, relative price volatility, and the real exchange rate. J. Int. Money Finance 29, 840–856.

Glosten, Lawrence, Jaganathan, Ravi, Runkle, David, 1993. On the relation between the expected value and the volatility of the normal excess return on stocks. J. Finance 48, 1779–1801.

Grier, Kevin, Smallwood, Aaron, 2007. Uncertainty and export performance: evidence from 18 countries. J. Money Credit Bank. 39, 965–979.

Grier, Kevin, Smallwood, Aaron, 2013. Exchange rate shocks and trade: a multivariate GARCH-M approach. J. Int. Money Finance 37, 282–305.

Grossmann, Axel, Love, Inessa, Orlov, Alexei, 2014. The dynamics of exchange rate volatility: a panel VAR approach. J. Int. Financ. Mark. Inst. Money 33, 1–27.

Hericourt, Jerome, Poncet, Sandra, 2013. Exchange rate volatility, financial constraints and trade: empirical evidence from Chinese firms. The World Economic Review 29, 550–578.

Huchet-Bouron, Marilyne, Korinek, Jane, 2011. To what extent do exchange rates and volatility affect trade?, vol. 119. OECD Trade Policy Papers: OECD Publishing, pp. 1–44, https://www.oecd-ilibrary.org/trade/to-what-extent-do-exchange-rates-and-their-volatility-affect-trade_5kg3slm7b8hg-en.

Johansen, Soren, 1991. Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. Econometrica 59, 1551–1580.

Klaassen, Franc, 2004. Why is it so difficult to find an effect of exchange rate risk on trade? J. Int. Money Finance 23, 817–839.

Ling, Shiqing, McAleer, Michael, 2002. Stationarity and the existence of moments of a family of GARCH processes. J. Econom. 106, 109–117.

Manova, Kalina, Wei, Shang-Jin, Zhang, Zhiwei, 2015. Firm exports and multinational activity under credit constraints. Rev. Econ. Stat. 97, 574–588.

McKenzie, Michael, 1999. The impact of exchange rate volatility on international trade flows. J. Econ. Surv. 13, 71–106.

Nishimura, Yusaku, Hirayama, Kenjiro, 2013. Does exchange rate volatility deter Japan-China trade? Evidence from pre- and post-exchange rate reform in China. Jpn. World Econ. 25–26, 90–101.

Robinson, Peter, 1991. Automatic frequency domain inference on semiparametric and nonparametric models. Econometrica 59, 1329–1363.

Tang, Hsiao Chink, 2014. Exchange rate volatility and Intra-Asia trade: evidence by type of goods. World Econ. 37, 335–352.

Yang, Guangpu, Gu, Qingyang, 2016. Effects of exchange rate variations on bilateral trade with a vehicle currency: evidence from China and Singapore. J. Int. Money Finance 68, 50–73.