Asymmetric volatility spillovers between economic policy uncertainty and stock markets: Evidence from China[1]

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Abstract: This study explores the spillovers between economic policy uncertainty (EPU) and stock market realized volatility (RV). The monthly index of Chinese and US EPU and RV are used to analyze the pairwise directional spillovers. We find that RV is a net receiver that is more vulnerable to shocks from U.S. EPU than to shocks from Chinese EPU. We further decompose the RV into good and bad volatility to test the asymmetric spillover effect between the stock market and EPU. The results suggest that EPU has a bigger effect on bad volatility in the stock market throughout most of the sample period. However, we find that good volatility spillovers become larger during periods of stimulated reform, whereas bad volatility spillovers become larger during periods of international disputes. We show that Chinese stock market volatility is sensitive to both U.S. and Chinese EPU and that the spillover is asymmetric in different periods.

Key words: Economic policy uncertainty; Realized volatility; Asymmetry spillover; Good and bad volatility

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1. Introduction

The rapid development of the Chinese stock market over the past decades has drawn much attention from academic researchers. The special characteristics of the "policy-driven" Chinese stock market, i.e., policy-makers adopt policies to alter the efficiency of the stock market, means that the risk of spillovers between policy changes and the stock market is high in China. Recently, as China has focused on a series of financial reforms including a deposit insurance system, interest rate liberalization, an exchange rate formation mechanism, and a science and technology innovation board, researchers have raised concerns about the effects of economic policy uncertainty (EPU). One branch of research uses the EPU index to examine the effect of EPU on different economic problems (Kang and Rattib 2013; Gulen and Ion 2016; Fontaine et al. 2018; Bakas and Triantafyllou 2018). The EPU index was developed by Baker et al. (2016), who first used newspaper coverage of economic and policy issues to quantify EPU. As EPU postpones corporate investment (Gulen and Ion 2016), increases corporate cash holdings (Demir and Ersan 2017), affects corporate innovation (He et al. 2020), harms bank liquidity creation (Berger et al., 2018), and drives management disclosure choices (Nagar et al. 2019). EPU has strong effects on economic activities (Gholipour and Hassan 2019). Based on the studies above, another branch of research focus on EPU and stock markets. EPU changes the expectations of the stock market (Pastor and Veronesi 2012), high EPU tends to decrease stock market excess returns (Arouri et al. 2016; Christou et al. 2017; Raza et al. 2018) and increase stock market volatility (Liu and Zhang 2015; Liu et al. 2017; Miao and Jinguo 2018; Yu et al. 2018). Luo and Zhang (2020) confirmed that EPU increases crash risk.

In today's global market, the role of EPU has become more significant and more complicated, not only due to the high policy uncertainty associated with China's financial market reforms (the EPU index of China is now twice as high as it was five years ago[2]) but also due to economic globalization, which has created more integrated financial markets. China has been involved in many international disputes in recent years, such as the Diaoyu Islands dispute and the trade dispute with the U.S. Therefore, this study focuses on the effect of international EPU on the Chinese stock market and attempts to identify the source of stock risk in the context of the integration of the world economy.

Although many studies have confirmed that EPU affects stock markets, the asymmetries in the stock market volatility spillovers from EPU have not yet received much attention. In this paper, we focus on downside risk. Downside risk is the risk of prices falling, which relates to an unfortunate event that causing low or negative return.

[2] http://www.policyuncertainty.com

Thus, getting returns in the lower tail of the return distribution constitutes this "downside risk." (Granger 2008). This could also been measured as value at risk or expected shortfall, which are typically estimated using daily returns. We measure the downside risk which proposed by Barndorff-Nielsen et al (2008) with semi-variance using high frequency data.

It is well documented that exogenous shocks, such as shocks in the oil market (Xu et al. 2019) or global financial markets (BenSaïda 2019), produce asymmetric responses in stock market volatility. Specifically, a negative exogenous shock to stock markets increases volatility more than a positive shock of the same magnitude; however, it remains unclear whether EPU transmits symmetric or asymmetrical risk spillovers to stock market volatility.

This study focuses on the asymmetrical effects of both domestic and international EPU on stock markets. As the U.S. has the strongest economy in the world, the U.S. EPU drives fluctuations in the world economy, with heterogeneous spillovers determined by the different characteristics of the receiving countries (Trung 2019). This study examines the mechanism through which the U.S. EPU influences the Chinese stock market. We use realized volatility (RV) to quantify stock market risk and use the spillover model (Diebold and Yilmaz 2012) to quantify the upside and downside risk spillovers. This model was improved by Baruník et al. (2016), who divided RV into positive realized semi-variance (RS^{+}) and negative realized semi-variance (RS^{-}) based on positive or negative returns using the definition of Barndorff-Nielsen and Shephard (2002) and Barndorff-Nielsen et al. (2008) .

We find that good volatility spillovers became larger during the periods of stimulated reform, whereas bad volatility spillovers became larger during the periods of international disputes. Some possible explanations are as follows. Firstly, bad volatility spillovers are larger than good volatility spillovers in most of time because investors have expectations about stimulated policies (Pastor and Veronesi 2012). If the stimulated policies are as good as expected, then the stock price will rise. Thus, in these periods, good volatility spillovers will be bigger than bad volatility spillovers. Secondly, Handley (2014) confirms that trade policy uncertainty will delay exporting. Feng et al. (2017) find that trade policy uncertainty can affect firm export decisions. Therefore, if exporting country's EPU increase, it will have a significant impact on Chinese macro-economic. Thus, during the periods of trade disputes, EPU contributes more to bad volatility rather than good volatility.

This study contributes to the literature in several ways. Firstly, although a lot of papers find that EPU could improve forecast accuracy of stock market volatility (Liu and Zhang 2015; Mei et al. 2018; Yu et al. 2018). However, these papers failed to clarify which country's EPU plays the most important role. Kido (2018) shows that the U.S. EPU results in shocks to global financial markets, but he studies equity return instead of volatility, which cannot measure stock market risk. Our paper captures the effect of international spillovers by adopting the spillover index developed by Diebold and Yilmaz (2012) and provides evidence of different spillover characteristics of the U.S. EPU and Chinese EPU on the Chinese stock market, which helps us to identify the Chinese stock market risk. We find that the U.S. EPU transmits more risk to the Chinese stock market than Chinese EPU. Thus, this paper identifies the source of the stock market risk. These results add to our understanding of the extent of international bi-directional risk spillovers.

Secondly, we divide realized volatility (RV) into positive realized semi-variance (RS^+) and negative realized semi-variance (RS^-) to test the different reactions of upside risk and downside risk to international EPU. Balcilar et al. (2019) concludes nonlinearity effects between EPU and volatility, but they do not check if there exists asymmetric effects. Yu and Song (2018) find that EPU have different forecast ability in different regimes, we argue in this paper that asymmetrical spillover might affect forecast accuracy. Our paper provide empirical evidences of asymmetrical spillovers, which help us to have a better understanding of the spillovers between EPU and stock markets risk.

In addition to its theoretical contributions, our study has practical value. We identify the time-varying characteristic of asymmetrical risk spillovers from EPU to stock market risk by using time rolling windows to reveal the dynamic spillover characteristics of international EPU on the Chinese stock market. We find that the spillover characteristics are different in periods of stimulated policies from those periods of international disputes. We find that during the period of financial crisis in 2008, the spillovers from the U.S. EPU were smaller than the spillovers from Chinese EPU; while in the other periods, the spillovers from the U.S. EPU were bigger than the spillovers from Chinese EPU. These results add to previous studies of stationary impact mechanisms (Liu and Zhang 2015; Mei et al. 2018; Yu et al. 2018) by examining spillovers under different market conditions. Besides, based on Handley (2014) and Feng et al. (2017), who find that trade policy uncertainty can affect export, our paper confirms that in the period of trade conflicts, bad volatility spillovers will become larger.

The rest of this paper is organized as follows. Section 2 presents the literature review. Section 3 presents the methodologies used to calculate the RV and asymmetrical spillover index. Section 4 reports the data, descriptive statistics and empirical results. Section 5 presents the robustness tests. Section 6 concludes the paper.

2. Literature Review

Many studies have emphasized the adverse effects of policy uncertainty. However, early studies lacked appropriate proxies for measuring policy uncertainty (Pawlina and Kort 2002; Pastor and Veronesi 2012). Since Baker et al. (2016) used newspaper coverage of economic and policy issues to construct an EPU index, it has become the benchmark for quantifying EPU and has allowed the expansion of studies of EPU.

Our study is related to at least three branches of research. The first branch examines the impacts of EPU on the macro-economy and enterprise behaviors. We focus on this branch because it considers how EPU affects stock markets and why the co-movement of EPU and stock markets is asymmetric, as it widely acknowledged that the theoretical prices of stocks are determined by the expectation of future cash flows and discount rates. Studies of the EPU's effects on the macro-economy have confirmed that EPU decreases outputs (Cheng 2017) and real loan growth (Bordo et al. 2016) and increases the unemployment rate (Caggiano et al. 2017). In terms of enterprise behavior, EPU makes firms more cautious and causes a "wait-and-see" effect, which means that EPU dampens the irreversible investment of corporations (Gulen and Ion 2016), especially small and medium-sized firms and in the period of recession (Kang et al 2014). In addition, EPU increases enterprises cash holdings, which can be viewed as a hedging instrument (Demir and Ersan 2017). These studies stress the negative impacts of EPU, implying that the stock market is more likely to undergo a downturn than to flourish.

The second branch of research directly examines the interactions between EPU and stock markets. These studies have identified the existence of an asymmetric and heterogeneous relationship between EPU and stock markets, but few studies have examined this relationship in detail. These studies have provided evidence of two aspects of the co-movement of EPU and stock markets: excess returns (Christou et al. 2017; Kido 2018; Guo et al. 2018; Raza et al. 2018; Das et al. 2019) and volatility (Liu and Zhang 2015; Liu et al. 2017; Yu et al. 2018; Su et al. 2019; He et al. 2020). Some studies have concentrated on the negative impact of EPU on stock market excess returns using VAR models (Christou et al. 2017; Kido 2018), others have applied a quantile approach and find that the co-movements of the lower and upper tails are heterogeneous (Guo et al. 2018; Raza et al. 2018; Das et al. 2019), implying an asymmetric and nonlinear effect between EPU and stock market returns. Some studies have focused on the forecasting promotion using HAR models (Liu and Zhang 2015) and GARCH-class models (Yu et al. 2018; Su et al. 2019). In addition, many studies have demonstrated the vital impact of U.S. EPU on receiving countries' stock markets (Christou et al. 2017; Das and Kumar 2018; Mei et al. 2018). They have shown that European stock markets (Mei et al. 2018) and developed stock markets (Das and Kumar 2018) are more sensitive to the U.S. EPU than to domestic EPU. Although these studies investigate the co-movements of EPU and stock markets, they do not consider the relative extent of spillovers from EPU to the upside risk and downside risk to stock markets.

The third branch of research reveals that exogenous shocks to stock markets are asymmetric. Investors do not significantly alter the discount rates on stocks during good times, but strongly revise the discount rates during bad times (Mele 2007), implying that stock markets are more volatile during recessions. Furthermore, Veronesi (1999) shows that stock prices underreact to good news in bad times. Medovikov (2016) confirms that stock markets have strong negative reactions to bad news but discount good news. Pastor and Veronesi's (2012) model illustrates that if investors expect the government to implement a stimulus policy, then the impact of the implementation of the policy on stock prices is limited, as it has already been priced into the market. However, if the policy is not implemented, stock prices plunge. These studies all indicate that EPU has an asymmetric effect on the stock market and that the co-movement with downside risk is more sensitive to EPU.

Since Barndorff-Nielsen and Shephard (2002) and Barndorff-Nielsen et al. (2008) divided the realized volatility (RV) into positive realized semi-variance (RS^+) and negative realized semi-variance (RS^-), the asymmetry of stock market reactions has received attention from researchers. Segal et al. (2015) define volatility with positive or negative innovations as good volatility and bad volatility, respectively. Baruník et al. (2016) use the spillover index model (Diebold and Yilmaz 2012) and the concept of good or bad volatility to develop an asymmetrical spillover index model. This model not only quantifies the bi-directional asymmetry but also reveals the dynamic characteristics of risk spillovers. The model has been applied in many studies (Baruník et al. 2016; Apergis et al. 2017; BenSaïda 2019; Xu et al. 2019). Our study uses this model to examine the asymmetric dynamic co-movement between EPU and stock markets.

3. Methodology

3.1 Good and Bad Volatility

Andersen and Bollerslev (1998) have developed a method for measuring stock market volatility that uses RV. This estimator is calculated using 5-min high-frequency data and captures dynamic fluctuations in stock markets.

To calculate RV, the first step is to calculate the stock market returns, which are the logarithmic differences in stock prices:

$$r_{d,j} = \ln(P_{d,j}) - \ln(P_{d,j-1}) = p_{d,j} - p_{d,j-1} \quad (1)$$

where r is the stock market returns, d is trading dates, j is trading periods, P is the stock price, and p is the logarithmic form of the stock price.

The second step is to calculate the daily stock market RV:

$$RV_d = \sum_{j=1}^{n} r_{d,j}^2 = \sum_{i=1}^{n} (p_{d,j} - p_{d,j-1})^2 \quad (2)$$

where n is the trading frequency. This equation means that the RV of a specific trading day is the sum of the returns of each trading period. We consider the vector of log-prices (p_0, …, p_n) that are equally distributed in the period [0, t]. Then, when $n \to \infty$,

$$\mathrm{RV} = \sum_{i=1}^{n} r_i^2 \to \int_0^t \sigma_s d_s + \sum_{0 \le s \le T} (\Delta p_s)^2 \quad (3)$$

The third step is to calculate RS. According to Barndorff-Nielsen and Shephard (2002) and Barndorff-Nielsen et al. (2008), assuming that the logarithmic form of the stock price is a continuous time stochastic process, when given a specific time [0≤t≤T], the log-price can be decomposed into a continuous and a pure jump component as follows:

$$p_t = \int_0^t \mu_s d_s + \int_0^t \sigma_s d_s + J_t \tag{4}$$

Adapted to some common filtration $\mathcal{F}$_t, μ is a locally bounded predictable drift process and σ is a strictly positive volatility process. Now define the jump as $\Delta p_t = p_t - p_{t-}$; then, Equation (4) can be rewritten as

$$[p]_t = \int_0^t \sigma_s d_s + \sum_{0\leq s\leq T} (\Delta p_s)^2 \tag{5}$$

As Barndorff-Nielsen and Shephard (2002) and Barndorff-Nielsen et al. (2008) decompose RV into semi-variances based on positive and negative returns, good and bad volatility can be defined as

$$\mathrm{RS}^+ = \sum_{i=1}^n r_i^2\, I(r_i > 0) \rightarrow \frac{1}{2}\int_0^t \sigma_s d_s + \sum_{0\leq s\leq T} (\Delta p_s)^2\, I(\Delta p_s > 0) \tag{6}$$

$$\mathrm{RS}^- = \sum_{i=1}^n r_i^2\, I(r_i < 0) \rightarrow \frac{1}{2}\int_0^t \sigma_s d_s + \sum_{0\leq s\leq T} (\Delta p_s)^2\, I(\Delta p_s < 0) \tag{7}$$

where I(•) is the indicator function, which is equal to one only if (•) is true. Therefore, $RV_t = RS_t^+ + RS_t^-$, and we can draw the conclusion that RV is the sum of RS^+ and RS^-. Note that we focus on the daily returns of the stock market to analyze the asymmetry of spillovers between RV and EPU because EPU is updated monthly and we decompose the volatility into good and bad as follows:

$$\mathrm{RS}^+ = \sum_{j=1}^m \sum_{i=1}^n r_{j,d}^2\, I(r_i > 0) \tag{8}$$

$$\mathrm{RS}^- = \sum_{j=1}^m \sum_{i=1}^n r_{j,d}^2\, I(r_i < 0) \tag{9}$$

where m is the number of trading days in a month, n is the measuring frequency in a day, and $r_{d,j}$ is the daily stock market returns.

3.2 Symmetrical Spillovers

To measure risk spillovers, we use the model developed by Diebold and Yilmaz (2012), which is based on a covariance stationary N-variable VAR model with P lag length. We focus on the H-step-ahead forecast error variance decomposition.

$$y_t = \sum_{i=1}^p A_i y_{t-i} + \varepsilon_i \tag{10}$$

where y is a vector of endogenous variables, including RV, Chinese EPU, and US EPU, and A_i is the coefficient matrix. ε_i~N(0,Σ) is a vector of independently and identically distributed disturbances. This formula can be transferred into a moving average form as follows:

$$y_t = \sum_{i=1}^\infty B_i\, \varepsilon_i \tag{11}$$

where $B_i = \sum_{j=1}^p A_{i-j} B_j$, and $B_0 = I_N$. If i<0, $B_i = 0$.

We can use Equation (11) to decompose the H-step-ahead forecast error variance and analyze the forecast error of variable y_i due to the shocks of variable y_j for i≠j, which is the core of spillover index. Accordingly, the H-step-ahead generalized forecast error variance decomposition shares are

$$\theta_{i,j}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i' B_h \Sigma e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' B_h \Sigma B_h' e_j\right)^2} \tag{12}$$

where H is the forecast step, Σ is the variance matrix of errors, σ_{jj} is the standard deviation of the error of the j-th equation, and ei is a selection column vector with a value of 1 for the i-th element, and 0 otherwise. For the shocks to each variable that are not orthogonalized, we have to normalize the variance decomposition shares to ensure that each array of the spillover matrix is equal to 1. In this case, $\tilde{\theta}_{i,j}(H) = \theta_{i,j}(H)/\sum_{j=1}^{N} \theta_{i,j}(H)$,where $\sum_{j=1}^{N} \tilde{\theta}_{i,j}(H) = 1$ for a specific j and $\sum_{i,j=1}^{N} \tilde{\theta}_{i,j}(H) = N$ We note that the spillovers of y_j that contribute to other variables are equal to $\sum_{j=1,i\neq j}^{N} \tilde{\theta}_{i,j}(H) = N$ for a specific j and the spillovers of y_i that are received from other variables are equal to $\sum_{i=1,i\neq j}^{N} \tilde{\theta}_{i,j}(H) = N$ for a specific i. Note that in our study, we normalize the shocks that y_j contributes to the forecast error of other variables to 1.

The total spillover index, based on Equation (13), which measures the contributions of all of the variables' shocks to the forecast errors of other variables or all of the variables' forecast errors received from other variables' shocks, can be computed as follows:

$$S(H) = \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\theta}_{i,j}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{i,j}(H)} = \frac{\sum_{i,j=1,i\neq j}^{N} \tilde{\theta}_{i,j}(H)}{N} \tag{13}$$

Based on Equation (12), the directional spillover index, which measures the forecast errors of a specific variable y_i received from other variables' shocks, can be computed using Equation (14), and the contributions of all of the variables' shocks to the forecast errors of a specific variable y_i can be computed using Equation (15).

$$S_{i\rightarrow\bullet}(H) = \frac{\sum_{j=1,i\neq j}^{N} \tilde{\theta}_{i,j}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{i,j}(H)} = \frac{\sum_{j=1,i\neq j}^{N} \tilde{\theta}_{i,j}(H)}{N} \tag{14}$$

$$S_{i\leftarrow\bullet}(H) = \frac{\sum_{i=1,i\neq j}^{N} \tilde{\theta}_{i,j}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{i,j}(H)} = \frac{\sum_{i=1,i\neq j}^{N} \tilde{\theta}_{i,j}(H)}{N} \tag{15}$$

Based on Equations (14) and (15), the net directional spillover index, Equation (16), which is the spillovers of a specific variable y_i to all of the other variables minus the spillovers of all of the other variables to the specific variable y_i.

$$S^n{}_i(H) = S_{i\rightarrow\bullet}(H) - S_{i\leftarrow\bullet}(H) \tag{16}$$

3.3 Asymmetric Spillovers

As Equations (5) to (8) can only calculate homogeneous risk between EPU and RV, we use the concept of asymmetries in volatility spillovers provided by Baruník et al.

(2016), who developed the model of Diebold and Yilmaz (2012). In this section, we consider the spillovers of EPU to good and bad volatility separately. We replace the vector of variable RV=(RV_1, RV_2,...,RV_t) with either the vector of negative semi-variances RS^- =(RS_1^- , RS_2^- ,..., RS_t^-) or of positive semi-variances RS^+=(RS_1^+,RS_2^+,...,RS_t^+) and construct the following VAR(p) models:

$$y_t^+ = \sum_{i=1}^{p} A_i y_t^+ + \varepsilon_t^+ \quad (17)$$

$$y_t^- = \sum_{i=1}^{p} A_i y_t^- + \varepsilon_t^- \quad (18)$$

where y_t^+ is a vector of Chinese EPU, U.S. EPU, and good volatility (RS^+) and y_t^- is a vector of Chinese EPU, U.S. EPU, and bad volatility (RS^-). Note that in our study, the EPUs are symmetric, and we do not divide it into good or bad volatility. As in Equations (13-15), we define the asymmetric total and directional spillovers of Equation (17-18) as ($S^+{}_i(H)$, $S^+{}_{i\to\bullet}(H)$, $S^+{}_{i\leftarrow\bullet}(H)$) and ($S^-{}_i(H)$, $S^-{}_{i\to\bullet}(H)$, $S^-{}_{i\leftarrow\bullet}(H)$) for good and bad volatility, respectively. We name the asymmetric spillovers positive spillovers and negative spillovers.

To reject the hypothesis that $S^+{}_i(H) = S^-{}_i(H)$, $S^+{}_{i\to\bullet}(H) = S^-{}_{i\to\bullet}(H)$, and $S^+{}_{i\leftarrow\bullet}(H)$=$S^-{}_{i\leftarrow\bullet}(H)$, which means that EPU and RV are not asymmetric spillovers, based on the framework of Baruník et al. (2016) we define the total and directional asymmetric spillovers as:

$$\mathrm{SAM}(H) = S^+(H) - S^-(H) \quad (19)$$

$$\mathrm{SAM}_{i\leftarrow\bullet}(H) = S_{i\leftarrow\bullet}^+(H) - S_{i\leftarrow\bullet}^-(H) \quad (20)$$

$$\mathrm{SAM}_{i\to\bullet}(H) = S_{i\to\bullet}^+(H) - S_{i\to\bullet}^- \quad (21)$$

If SAM is not equal to zero, there remains an asymmetric effect between RV and EPU. We expect the negative $\mathrm{SAM}_{i\leftarrow\bullet}$, implying that EPU contribute more to bad volatility (RS^-) than to good volatility (RS^+).

4. Results

4.1 Data

We analyze the spillovers between Chinese EPU, the U.S. EPU, and realized volatility (RV) on the Shanghai Stock Exchange Composite index. We obtain the monthly EPU indices developed by Baker et al. (2016)[3] and the RV indices.[4] The sample period is from January 2000 to March 2019, and it includes 231 months. We transform these data into logarithmic forms.

We list the descriptive statistics in Table 1. Panel A gives the descriptive statistics for EPU and Panel B gives the descriptive statistics for realized volatility (RV) or realized semi-variance (RS). The Augmented Dickey–Fuller Test and Phillips–Perron

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3 http://www.policyuncertainty.com/

4 http://www.realized. oxford-man.ox.ac.uk/

Test both reject the null hypothesis and all of the variables are stationary. From Panel A, we note that the logarithmic form of the Chinese EPU is higher and more volatile than that of the U.S. EPU, implying that policies change more often in China. From Panel B, we note that the logarithmic form of RS^+ is higher and more volatile than that of RS^-, implying a higher downside risk for the Chinese stock market.

Insert Table 1 here

4.2 Full sample analysis

We list the results of the analysis of the full sample in Table 2. We concentrate on the off-diagonal elements rather than the diagonal elements because they show the different characteristics of the directional spillovers. Noting that we normalize the contributions to 1, the row of the elements (i, j) shows the spillovers of shocks to i that contribute to the forecast error of j, and the column of the elements (j, i) shows the spillovers that forecast error of j receives from shocks to i. Model 1 is a symmetric analysis to determine whether the Chinese stock market is more sensitive to domestic EPU or to the U.S. EPU. The volatility of the Chinese stock market leads to a lower risk of spillovers. Furthermore, the pairwise risk of spillovers between realized volatility (RV) and the U.S. EPU is (10.35%), which is higher than the pairwise risk of spillovers between realized volatility (RV) and domestic EPU (5.89%), implying that as the Chinese stock market becomes globalized, it suffers more risk from the U.S. EPU. The U.S. is a net contributor to policy uncertainty, which drives the risk to the Chinese stock market, and China is a net recipient, playing a limited role. This occurs because the U.S. is a developed country that is at the center of social, economic, and political activities (Trung 2019).

Models 2 and 3 are asymmetric analyses of good volatility and bad volatility, respectively. They examine whether downside risk is more sensitive to EPU than upside risk. There are more spillovers between EPU and RS^- (30.22%) than between EPU and RS^+ (25.64%), indicating a higher bi-directional co-movement with bad volatility. As in Model 1, good and bad volatility remain net recipients that are more sensitive to the U.S. EPU. However, the receiving structure has changed. The spillover rate of EPU to upside risk is only 1.87%, whereas the spillover rate of EPU to downside risk is 9.93%, demonstrating the intense asymmetric transmission of spillovers between EPU and stock market volatility. This finding confirms that EPU amplifies the downside risk but has a limited role in upside risk.

Insert Table 2 here

4.3 Rolling-windows analysis

4.3.1 Symmetric risk spillovers

To capture the time-varying characteristic of risk spillovers, we use the symmetric risk spillovers model constructed by Diebold and Yilmaz (2012) to analyze 72-month window rolling samples with 6-month step ahead forecast errors. We use a subsample of a six-year period, which is about one-third of the complete dataset's duration.

Figure 1 presents the time-varying spillover index of the symmetric model. We note the specific trend in total spillovers: the total spillover index has a maximum extreme point at the time of the financial crisis. It remains higher than 50% until 2011 but experiences a significant plunge near 2013 of about 20%. It then begins to rise, but it remains lower than before, and has only recently stabilized near 40%. To determine why the total spillover index presents this specific trend, we focus on the directional spillovers.

We find that the spillovers from stock market risk to EPU declined after 2012, perhaps because during the period of "The 12th Five-Year Plan," the People's Bank of China focused on the development and reform of the financial sector, particularly interest rate liberalization and exchange rate formation mechanism. These reforms consisted of a series of reform programs including a deposit insurance system and market exit mechanism for financial institutions, which caused the Chinese EPU to rise sharply. The reforms were not focused on the stock market as an anchor, as the government concentrated on financial supply, so spillovers declined.

In terms of domestic policy-making, we find that the stock market had a relatively higher risk of spillovers from EPU during the 2008 to 2010 period, but this dropped in 2013. This is similar to the trend seen in the total spillover index, probably because from 2008 to 2010, China expanded domestic demand in response to the financial crisis. This included a four trillion investment plan, which revived the stock market and most of the local debts expired around 2013. The Diaoyu Island dispute started in 2012, causing high uncertainty; however, the data show limited spillovers to the stock market. In January 2016, China used circuit breakers, causing a plunge in the stock market, and the data show high spillover rates at that time.

In terms of the U.S. policy-making, we find that during financial crises, the Chinese stock market becomes more sensitive to the U.S. EPU. In 2013, when the U.S. adjusted its fiscal policy, the deficit dropped markedly and the spillovers increased. After Trump's election, the spillovers decreased because the series of reforms in the U.S. in recent years have not created much spillover risk to the Chinese stock market. After the series of reforms in the 12th Five-Year Plan, the Chinese EPU became less of an influence on the Chinese stock market, which became more sensitive to global events.

Insert Figure 1 here

4.3.2 Asymmetric risk spillovers

To capture the time-varying characteristic of asymmetric risk spillovers, we decompose realized volatility (RV) into good volatility and bad volatility and use apply the model constructed by Baruník et al. (2016) to 72-month window rolling samples with 6-month-ahead forecast errors.

Figure 2 presents the time-varying spillover index of the asymmetric model. A positive (negative) value suggests that the EPU has a bigger (smaller) effect on good volatility than on bad volatility. We note that the two semi-variances express similar trends but with different intensities. Consistent with our expectation, during most of the sample period, the spillovers of bad volatility are larger, implying that the same magnitude of EPU shock usually has a bigger effect on downside risk than on upside risk. The finding that EPU causes less volatility for positive return supports the theoretical prediction that EPU has a limited effect on increases in stock prices because they are expected and priced into the market before the policies are implemented (Pastor and Veronesi 2012).

The risk spillovers are time-varying. Specifically, during periods of international dispute, such as the Diaoyu Island dispute or the trade dispute with the U.S., EPU has a strong effect on downside risk, but a limited effect on upside risk. This result demonstrates the strong asymmetry in the co-movement of EPU and the stock market. During the period of stimulative reforms, such as fiscal policy adjustments in the U.S., the four trillion investment plan, or the 12th Five-Year Plan of financial reform in China, EPU had a bigger effect on the upside risk. The asymmetry is greater under supply-side reform (financial reform) than under demand-side reform (four trillion investment plan).

Insert Figure 2 here

5. Robustness check

In Figure 3, we use different rolling window widths and forecast horizons to check the robustness of our findings. In the upper panel, forecast horizons are changed to 12; in the middle panel, forecast windows are changed to 90; and in the lower panel, lags are changed to 6.

All of the results show that during most of the sample period, EPU usually has a bigger effect on downside risk and the characteristics of specific events remain robust. During the period of stimulative reform, upside risk is more sensitive to EPU than downside risk, whereas during the period of international disputes, downside risk becomes more sensitive. These tests show that our conclusions are robust.

Insert Figure 3 here

6. Conclusion

Due to financial globalization, government policy-making has global implications (Balli et al. 2017). As the U.S. policies strongly influence the Chinese stock market (Li and Peng 2017), this study examines the U.S. EPU's impact on the Chinese stock market. We focus on downside risk, which relates to an unfortunate event occurring and cause low or negative return. Using 5-min high-frequency data from the Shanghai stock market composite index and the EPUs of China and the U.S. for the January 2000 to March 2019 period, we use the spillovers models initial constructed by Diebold and Yilmaz (2012) and improved by Baruník et al. (2016) to investigate the dynamic and asymmetric relationship between EPU and stock markets. This study extends our understanding of the mechanism through which foreign EPU influences the Chinese stock market risk by decomposing realized volatility (RV) into good and bad semi-variances based on stock market returns, which allows us to capture the dynamic and complete trading information and identify quantitative time-varying pairwise risk spillovers.

Our conclusions are as follows. First, stock market realized volatility (RV) is a net recipient. This means that EPU dominates stock market risk, whereas stock market risk has little effect on EPU. Furthermore, we quantify the spillovers which can be used to compare the different characteristic of the spillovers. It could also be used to identify the source of stock market risk. The U.S. EPU has a bigger effect on the Chinese stock market than Chinese EPU. Second, EPU has a bigger effect on downside risk than on upside risk for most of the study period, which means that if the stock return of the day is negative, it is more vulnerable to the shocks from EPU. Third, the risk spillovers between EPU and stock market volatility are time-varying. During the periods of stimulative reforms, such as fiscal policy adjustments in the U.S., China's four trillion investment plan, or the 12th Five-Year Plan's financial reforms, upside risk is more sensitive to EPU than downside risk, whereas during periods of international dispute, such as the Diaoyu Island dispute or the trade dispute with the U.S., downside risk is more sensitive than usual.

The topic of risk spillovers between EPU and stock markets has recently received attention from international investors, policy makers, and researchers. The improved asymmetric spillover model indicates that international investors and policy makers should pay attention to the adverse effects of EPU on downside stock market volatility.

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Table 1. Descriptive statistics and unit root tests

Notes: The statistics are in monthly logarithmic form. We test whether the variables are stationary using the Augmented Dickey–Fuller Test and Phillips–Perron Test. The null hypothesis is that the variable has a unit root. ** indicates significance at the 5% level and *** indicates significance at the 1% level.

	Obs.	Mean	Max.	Min.	Std. Dev.	Skewness	Kurtosis	PP	ADF
Panel A: Monthly EPU indices.									
Chinese EPU	231	4.8628	6.8409	2.2046	0.7754	0.0668	3.2631	-8.3776***	-3.8214**
US EPU	231	4.7463	5.6495	3.8018	0.3727	0.0158	2.7127	-5.7727***	-6.1163***
Panel B: Monthly RV indices.									
RV	231	-6.1457	-3.5217	-8.0781	0.9216	0.4049	2.7084	-4.9859***	-5.2692***
RS^+	231	-6.8695	-4.4470	-9.6265	0.9656	0.2469	2.6394	-5.3782***	-4.0827***
RS^-	231	-6.8705	-3.9496	-8.8275	0.9500	0.4287	2.9438	-5.8164***	-4.8404***

Table 2. Full sample analysis

Notes: This table provides the results of the analysis of the full sample. All of the results are given in percentages and all of the variables are in logarithmic form. The model includes 3 lags, based on AIC. The row indices of each country are normalized. "To" indicates the contributor and "From" indicates the receiver. "S" refers to the total spillover index. There are 231 observations.

Model 1	RV	Chinese EPU	US EPU	To	Net	direction
RV	97.26	1.55	1.18	0.91	-4.50	Net-recipient
Chinese EPU	5.89	87.83	6.29	4.06	-15.52	Net-recipient
US EPU	10.35	57.19	32.46	22.51	20.02	Net-contributor
From	5.41	19.58	2.49	S=27.48		
Model 2	RS^+	Chinese EPU	US EPU	To		direction
RS^+	96.14	2.74	1.13	1.29	-0.54	Net-recipient
Chinese EPU	1.83	92.38	5.79	2.54	-18.93	Net-recipient
US EPU	3.78	61.67	34.55	21.82	19.51	Net-contributor
From	1.87	21.47	2.30	S=25.64		
Model 3	RS^-	Chinese EPU	US EPU	To		direction
RS^-	96.26	1.57	2.17	1.25	-8.68	Net-recipient
Chinese EPU	10.13	82.93	6.94	5.69	-11.56	Net-recipient
US EPU	19.65	50.18	30.17	23.28	20.24	Net-contributor
From	9.93	17.25	3.04	S=30.22		

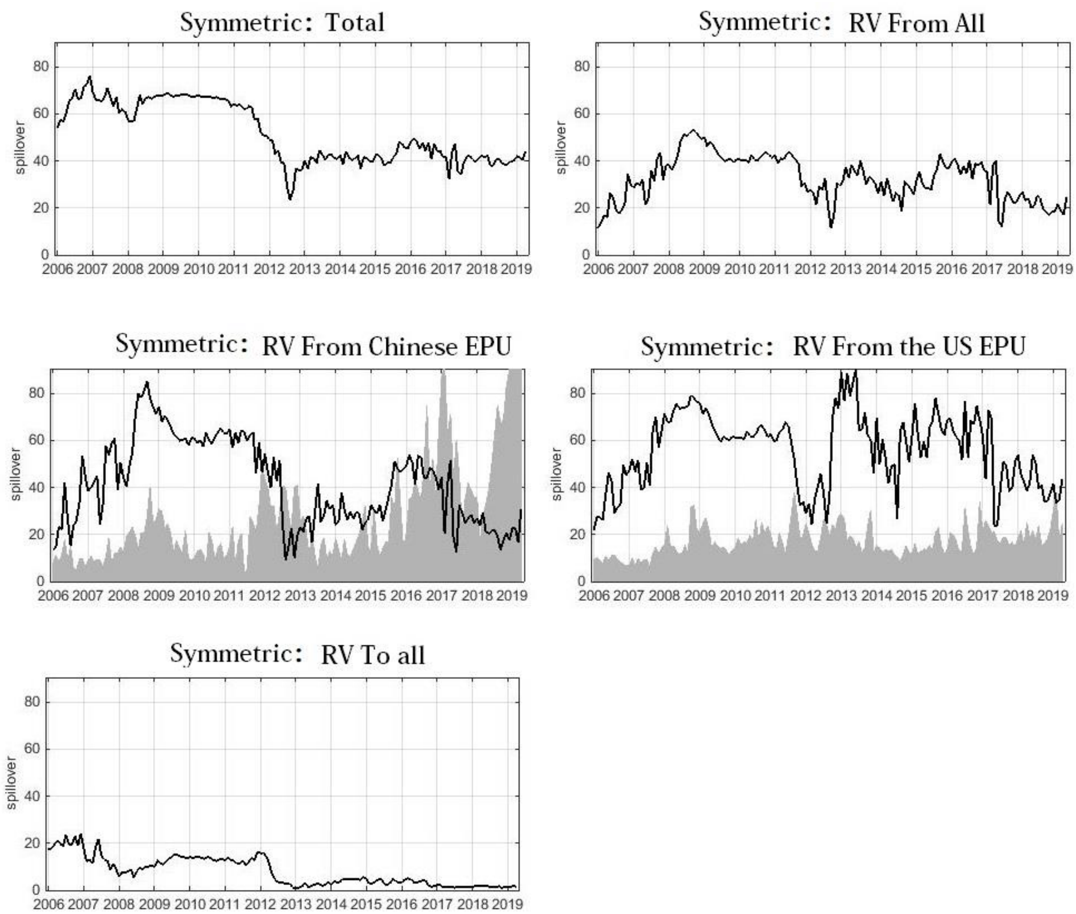

Figure 1. Symmetric risk spillovers.

Notes: All of the results are in percentages and all of the variables are in logarithmic form. The model includes 3 lags. Forecast step is 6-month.

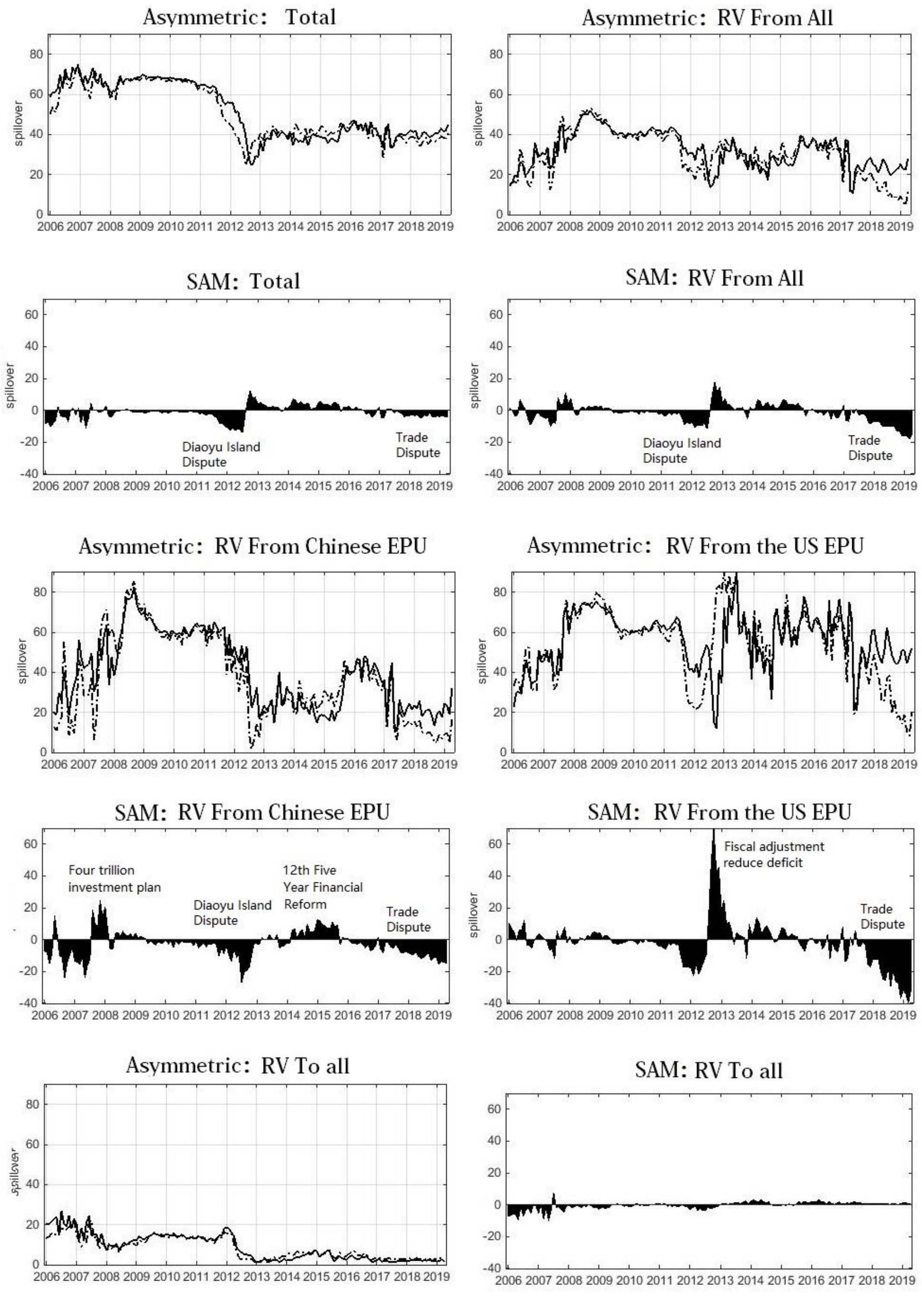

Figure 2. Asymmetric risk spillovers.

Notes: All of the results are in percentages and all of the variables are in logarithmic form. The model includes 3 lags. Forecast step is 6-month.The upper panel captures the spillovers of good volatility (Dotted line) and. bad volatility (Solid line). The lower panel captures the asymmetric risk of spillovers.

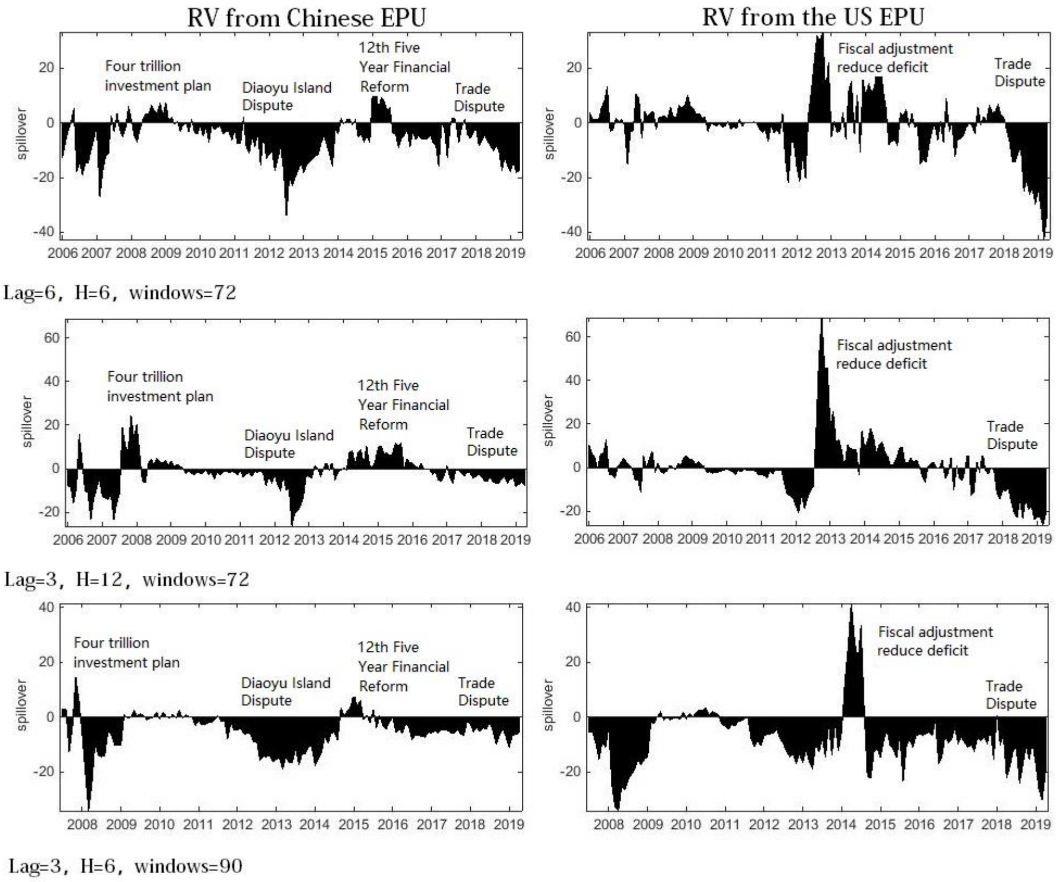

Figure 3. Robustness check of asymmetric risk spillovers.

Notes: All of the results are in percentages and all of the variables are in logarithmic form. We change the lags to 6, the forecast horizon to 12, and the window to 90.