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Risk Transmissions between Major Foreign Currencies: An Empirical Analysis from the U.S. Perspective

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Abstract

This study investigates volatility spillovers and extreme return movements between major foreign currencies and examines how they vary over time with a focus on the 2007 Global Financial Crisis. Our results show that volatility spillovers become more significant during the post-crisis period. Also, considering the effect of the 2016 U.K. referendum known as Brexit on volatility spillovers, we find that volatility spillovers from the British pound (GBP) to other major currencies are weakened after the 2016 referendum whereas those from other major currencies to GBP remain the same regardless of the referendum. On the other hand, we discover that extreme return movements between major currencies are weakened during the post-crisis period and extreme returns on European currencies are more simultaneously tied together than other major currencies in geographically different economies.

Keywords: Volatility Spillovers; Extreme Return Movements; Global Financial Crisis; Brexit

JEL Classification: C13; F31

1. Introduction

As the globalization of financial markets has been accelerated and international trades have sharply increased over the past decades, geographically different economies around the world have become more closely tied together. As a result, financial market participants have been increasingly concerned about volatility or downside risk across international financial markets.

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There have been a lot of studies that focus on financial contagion in financial markets and thus, volatility spillovers in local and global stock markets have been heavily explored. Diebold and Yilmaz (2009) propose separate measures of return and volatility spillovers. Using 19 global equity market data, they find that volatility spillovers show no tendency, but distinct bursts closely related to market crashes. Abidin and Zhang (2011) find that there exist significant volatility spillovers across five major Asia Pacific stock markets. Mozumder *et al*. (2015) examine volatility spillovers between stock markets and exchange rate markets and identify significant spillover effects in both developed and emerging countries. Jebran and Iqbal (2016) investigate volatility spillovers between stock and foreign exchange markets in Asian countries and find that there exist bidirectional volatility spillover effects in Pakistan, China, Hong Kong, and Sri Lanka whereas there exists unidirectional volatility spillover from the stock market to the foreign exchange market in India. Jebran *et al*. (2017) focus on the 2007 Global Financial Crisis and find that there exist bidirectional volatility spillovers among five emerging stock markets in Asia. Jebran (2018) also examines the volatility transmission between stock and foreign exchange markets in China with a focus on the 2007 financial crisis and finds that while the pre-crisis period shows unidirectional volatility transmission from the stock market to the foreign exchange market, the post-crisis period shows bidirectional volatility transmission between stock and foreign exchange markets. Jain and Sehgal (2019) investigate volatility spillovers between developed equity markets with a focus on the 2007 Global Financial Crisis (GFC) and identify the reduced impact of the U.S. on the other developed markets.

Also, many studies investigate volatility transmissions between the U.S. stock market and other stock markets. Öztürk and Volkan (2015) investigate volatility spillover effects between the U.S. stock market and the MENA (Middle East and North African) stock markets and find that the MENA markets are relatively little exposed to volatility transmission from the U.S. market and to some degree, these markets are still globally isolated. Jawadia *et al*. (2015) show that volatility spillovers between the U.S. stock market and three European stock markets are strengthened after the recent (2007) financial crisis. Sun *et al*. (2015) study volatility spillover effects across the U.S., U.K., and Canadian stock markets and discover that volatility spillover effects are reinforced during high movements in currency markets. Li and Giles (2015) examine volatility spillovers in the U.S., Japan, and Asian emerging stock markets and find that volatility spillover effects between the U.S. market and the other markets become stronger after the recent (2007) financial crisis. More studies identify and analyze volatility spillovers associated with stock markets (Yang and Doong, 2004; Baele, 2005; Malika and Hammoudeh, 2007; Galloa and Otranto, 2008; Savva *et al*., 2009; Asgharian and Nossman, 2011; Jiang *et al*., 2012; Wang *et al.,* 2018). In addition, some studies expand volatility spillover effects to bond markets, oil markets, and commodity markets (Christiansen, 2007; Du *et al*., 2011; Wu *et al*., 2011).

However, there have been few studies that examine volatility spillovers across currency markets, especially with a focus on the 2007 Global Financial Crisis. Baillie and Bollerslev (1990) find that volatility patterns of exchange rate returns are similar based on hourly data and fail to identify significant volatility spillovers between different currencies. Using data from 1986 to 2012, Antonakakis (2012) shows that volatility spillovers across four major currencies are significant and bidirectional before and after the introduction of Euro. Rajhans and Jain (2015) investigate volatility spillover effects among major currency pairs using data from 2008 to 2012 and discover that on average, volatility spillover effects are not strong during this time period and CAD is a net transmitter while GBP and AUD are net receivers.

On the other hand, although there have been a large number of studies on return movements, most of them examine equity markets rather than currency markets and attempt to compare and explain return movements in terms of economic fundamentals, pricing, or behavioral factors (Chan *et al*., 2007; Green and Hwang, 2009; Rua, and Nunesb, 2009; Didier *et al*., 2012; Höchstötter *et al*., 2014; Deng, 2016; Baek 2016).

To sum up, although the risk in equity markets has been extensively studied, volatility spillovers between foreign currency markets have not been vigorously examined. In addition, despite the fact that the 2007 Global Financial Crisis greatly impacted financial markets in all aspects, little research has been conducted about foreign currency market volatilities focusing on the 2007 Global Financial Crisis. Furthermore, to the best of our knowledge, almost no research has attempted to identify the effect of the 2016 U.K. referendum known as Brexit on the British pound (GBP) in terms of volatility spillover effects. Thus, we are strongly motivated to make up for these deficiencies in the existing literature.

In this study, we investigate volatility spillovers between major foreign currencies with a focus on the 2007 Global Financial Crisis and consider the effect of the 2016 U.K. referendum. Also, we examine extreme return movements in major foreign currency markets. Even if returns on different currencies appear to move similarly or randomly during normal times, it doesn't necessarily mean that they also move in the same manner during bad times. Examining extreme returns provides information about how simultaneously returns deteriorate during extreme market downturns. Since we use currency values quoted in the U.S. dollar, our study represents the U.S. perspective.

Our results show some new findings and have significant implications in several aspects. First, we find that volatility transmissions between major foreign currencies become more significant after the 2007 Global Financial Crisis. In addition, while these transmissions tend to be bidirectional only across geographically close currencies before the crisis, they tend to be bidirectional across most of the currencies after the crisis. This is inconsistent with Rajhans and Jain (2015) who use very limited data around the 2007 Global Financial Crisis. Second, GBP is most significantly and negatively affected by the 2016 U.K. Referendum, which means that volatility transmissions from GBP to other major currencies are significantly weakened after the referendum. Although the actual Brexit is still up in the air, this result is expected to provide investors or policy makers with useful information if the actual Brexit occurs. Third, during market downturns, extreme return co-movements between major currencies tend to be weakened after the 2007 Global Financial Crisis. This might be associated with hedging or policy changes made after the crisis. Also, extreme returns on geographically close currencies appear to be more simultaneously tied together during severe market downturns. This can be expected but we support it with empirical evidence. Since there are not many previous studies about currency market volatilities and extreme returns and they also simply focus on currency volatility spillovers given data regardless of influential market events, our results are relatively new and make some significant contributions to the literature. In particular, our results about volatility spillovers and the patterns of extreme return movements between major currencies are expected to be very useful to financial market participants in terms of risk diversification or policy development. We describe all data in Section 2 and show methods and empirical results in Section 3. Then, we conclude in Section 4.

2. Data

We obtain daily currency data from the Federal Reserve Bank of St. Louis. Our data consist of five major foreign currencies quoted in the U.S. dollar from January 2, 2002 to December 30, 2016. Five major currencies are Euro (EUR), British pound (GBP), Japanese yen (JPY), Canadian dollar (CAD), and Swiss franc (CHF). We divide the entire data period into two sub-periods by the 2007 Global Financial Crisis.

Table 1. Descriptive Statistics – Daily Returns

	EUR	GBP	JPY	CAD	CHF
Panel A: Pre-crisis period from January 2, 2002 to October 9, 2007					
Mean	0.00030918	0.00023820	0.00008207	0.00033511	0.00022694
Standard deviation	0.00552412	0.00504984	0.00579434	0.00493720	0.00624516
Maximum	0.01935825	0.02093030	0.02931351	0.01749051	0.02096646
Minimum	-0.02114417	-0.02170713	-0.02451899	-0.01588970	-0.02408143
Panel B: Post-crisis period from October 10, 2007 to December 30, 2016					
Mean	-0.00012695	-0.00021793	0.00000144	-0.00013541	0.00006493
Standard deviation	0.00669185	0.00681347	0.00701188	0.00671848	0.00776085
Maximum	0.04620792	0.04434858	0.05215648	0.05071599	0.13022245
Minimum	-0.03003101	-0.08169384	-0.03342812	-0.03806962	-0.08890689

Jawadia *et al*. (2015) detect one significant structural breakpoint during the recent financial crisis based on the Bai-Perron structural break test and confirm that it is October 9, 2007. We adopt the same structural break date to break down our data period into two sub-periods: pre-crisis period from January 2, 2002 to October 9, 2007 and post-crisis period from October 10, 2007 to December 30, 2016. Table 1 shows descriptive statistics of daily returns on five major foreign currencies. Overall, mean returns decrease and standard deviations increase during the post-crisis period. Notably, while CHF has the largest standard deviation across both periods, CAD has the highest increase in its standard deviation. The United Kingdom decided to leave the European Union by a referendum held on June 23, 2016, which is broadly known as Brexit. We examine the effect of the 2016 referendum on volatility spillovers between major foreign currencies by splitting the post-crisis period into another two sub-periods: pre-referendum period from October 10, 2007 to June 23, 2016 and post-referendum period from June 24, 2016 to December 30, 2016. Since influential events tend to have a significant impact on financial markets over a short time period rather than a long time period, this enables us to identify the short-term effect of the 2016 U.K. referendum on major currencies.

3. Methods and Empirical Results

The main purpose of our study is to investigate volatility spillover effects between major foreign currencies during the pre- and post-crisis periods. To do this, we establish mean and variance equations for their return series. Most studies construct volatility models on the basis of the generalized autoregressive conditional heteroskedasticity (GARCH) process because it is well known that volatilities of financial time series tend to be serially correlated and heteroskedastic.

Figure 1. Currency Returns

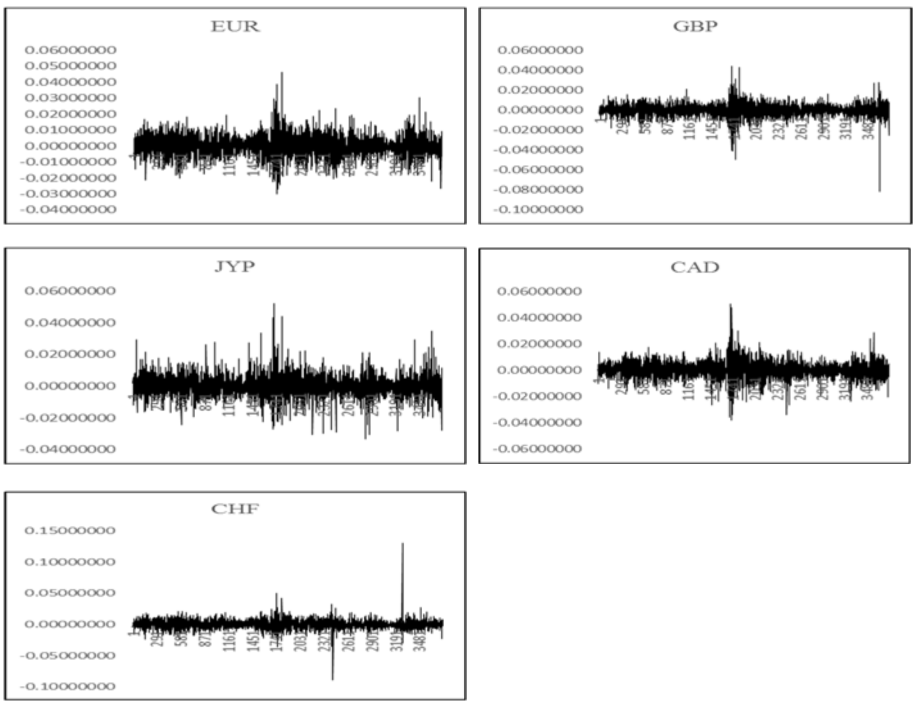

Figure 1 shows daily returns for each currency and all five major currencies appear to have time-varying volatility clustering. This supports the use of GARCH-type models. We employ an AR-GARCH model with exogeneous variables. The autoregressive (AR) model is constructed for the currency mean equation as follows.

$$r_{it} = a + \sum_{j=1}^{p} b_{ij} L^j r_{it} + \varepsilon_{it} \tag{1}$$

$$\varepsilon_{it} | \Omega_{it-1} \sim N(0, \xi_{it}^2)$$

where r_{it} is the currency i's return at time t, p is the number of lags, L^j is a lag operator, and Ω_{it-1} is an information set at time t-1. Since the variance equation needs to incorporate time-varying volatilities, the GARCH process is constructed for volatilities. Then, the variance equation includes squared errors from Equation (1) as exogenous variables to see if there exist volatility spillovers between major currencies. Since we also attempt to examine how volatility spillover effects vary before and after the 2016 U.K. referendum, we add referendum dummies as exogenous variables. Ferenstein and Gasowski (2004) show details for the AR-GARCH model.

$$\xi_{it}^2 = \alpha + \sum_{j=1}^{p} \beta_j L^j \varepsilon_{it}^2 + \sum_{j=1}^{q} \gamma_j L^j \xi_{it}^2 + \sum_{k \neq i}^{n} (\delta_k + \lambda_{RX,k} D_{RX}) \varepsilon_k^2 \tag{2}$$

where ε_k^2 are squared errors of currency k and D_{RX} is the referendum dummy that equals 1 if t is after June 23, 2016 and 0 otherwise. Since Equation (1) and Equation (2) constitute one system of mean and variance equations, we estimate all coefficients simultaneously using the maximum likelihood and a quasi-Newton method. In fact, since the GARCH (1, 1) was most widely adopted by previous studies and coefficients in Equation (2) often do not properly converge with more than one lag in the GARCH term, we also adopt the GARCH (1, 1) process. Table 2 shows results. First of all, we find that the number of significant delta (δ) coefficients for all five major currencies increases for the post-crisis period. This means that volatility spillovers become more significant during the post-crisis period than the pre-crisis period. Since all statistically significant delta coefficients are positive, this provides evidence that volatilities between major currencies are positively transmitted. We discuss each currency and the effect of the referendum in more detail.

Table 2. Volatility Spillovers

DV	α	β	γ	δ_{EUR}	δ_{GBP}	δ_{JPY}	δ_{CAD}	δ_{CHF}	$\lambda_{RX,EUR}$	$\lambda_{RX,GBP}$	$\lambda_{RX,JPY}$	$\lambda_{RX,CAD}$	$\lambda_{RX,CHF}$
Panel A: Pre-crisis period from January 3, 2002 to October 9, 2007													
EUR	0.000001 (5.23***)	0.003123 (0.31)	-0.006916 (-0.67)	-	0.072677 (3.38***)	0.011690 (1.67*)	0.037082 (3.43***)	0.661260 (16.75***)	-	-	-	-	-
GBP	0.000006 (7.98***)	0.022883 (1.23)	0.024104 (0.93)	0.229630 (3.58***)	-	0.043802 (2.57**)	0.007258 (0.44)	0.274250 (5.20***)	-	-	-	-	-
JPY	0.000017 (8.76***)	0.038212 (1.70*)	0.017534 (0.35)	0.063781 (0.77)	0.144340 (2.61***)	-	0.005097 (0.16)	0.25497 (3.66***)	-	-	-	-	-
CAD	0.000012 (6.09***)	0.013640 (0.57)	0.203200 (2.34**)	0.219080 (3.54***)	0.035123 (1.02)	0.013905 (0.81)	-	-0.008401 (-0.19)	-	-	-	-	-
CHF	0.000002 (6.26***)	-0.001494 (-0.15)	0.003651 (0.32)	1.099900 (17.40***)	0.057600 (2.54**)	0.025049 (2.34**)	-0.001549 (-0.18)	-	-	-	-	-	-
Panel B: Post-crisis period from October 10, 2007 to December 30, 2016													
EUR	0.000002 (5.41***)	0.035389 (3.97***)	0.001823 (0.36)	-	0.172310 (7.28***)	0.025956 (2.48**)	0.070003 (4.45***)	0.636100 (16.87***)	-	-0.138520 (-3.96***)	-0.035828 (-3.08***)	-0.040627 (-0.67)	0.133230 (0.77)
GBP	0.000002 (4.11***)	-0.000098 (-0.15)	0.400760 (12.65***)	0.240350 (9.18***)	-	0.074128 (4.92***)	0.174580 (7.47***)	-0.003192 (-1.59)	0.173280 (0.59)	-	-0.038292 (-0.53)	0.426260 (1.93*)	0.195740 (0.66)
JPY	0.000013 (8.50***)	0.073039 (3.51***)	0.176070 (4.13***)	0.083033 (2.24**)	0.191730 (5.10***)	-	0.083118 (3.12***)	0.153450 (4.68***)	-0.493190 (-2.40**)	-0.179470 (-3.97***)	-	-0.043927 (-0.26)	1.517600 (3.51***)
CAD	0.000003 (4.85***)	0.091982 (4.29***)	0.347710 (9.17**)	0.140470 (5.21***)	0.272960 (7.76***)	0.053587 (3.37***)	-	0.021607 (1.74*)	-0.114690 (-0.81)	-0.207860 (-3.63***)	-0.030629 (-0.67)	-	0.225690 (1.27)
CHF	0.000001 (2.22**)	0.099074 (4.60***)	0.158460 (7.14***)	0.858870 (16.76***)	0.035813 (1.85*)	0.066352 (4.31***)	0.030526 (2.03**)	-	-0.246110 (-1.79*)	-0.057565 (-2.76***)	-0.029652 (-1.02)	0.018004 (0.35)	-

DV – Dependent Volatility
*, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

EUR: When EUR (volatility) is a dependent variable, EUR is significantly affected by all other currencies across both periods because delta coefficients of other currencies are all statistically significant. Also, since $\delta_{EUR}$is statistically significant across both periods and all currencies except only for JPY in the pre-crisis period, volatilities are transmitted from EUR to all other currencies.

GBP: GBP is significantly affected by all other currencies except for CAD in the pre-crisis period and CHF in the post-crisis period. Similarly, based on the significance of δ_{GBP}, GBP influences all other currencies except for CAD in the pre-crisis across both periods.

JPY: JPY is significantly affected by GBP and CHF during the pre-crisis period whereas it is significantly affected by all other currencies during the post-crisis period. Also, δ_{JPY} influences all other currencies except only for CAD in the pre-crisis period across both periods.

CAD: While CAD is significantly affected only by EUR during the pre-crisis period, it is affected by all other currencies during the post-crisis period. Also, δ_{CAD} influences only EUR during the pre-crisis period and all other currencies during the post-crisis period.

CHF: While CHF is significantly affected by all other currencies across both periods except only for CAD in the pre-crisis period. δ_{CHF} influences all other currencies except for CAD in the pre-crisis period and GBP in the post-crisis period.

2016 U.K. Referendum (Brexit): To see the effect of the 2016 U.K. referendum on volatility spillovers, we focus on spillover effects between GBP and other major currencies. In Panel B, $\lambda_{RX,GBP}$ is negatively significant across all other currencies, which means that volatility transmissions from GBP to other currencies are weakened after the referendum.

One possible explanation may be investors' migration from GBP to other major currencies after the referendum. The link between GBP and other major currencies would be eroded and thus, volatility transmissions from GBP to other major currencies are likely to be reduced. Based on our data, average daily returns of EUR, GBP, JPY, CAD, and CHF during the post-referendum period are -0.06%, -0.14%, -0.08%, -

0.04%, and -0.05%, respectively. This shows that GBP significantly lost its value relative to other currencies after the referendum. These observations support our explanation. However, $\lambda_{RX,EUR}$, $\lambda_{RX,JPY}$, $\lambda_{RX,CAD}$, and $\lambda_{RX,CHF}$ with respect to GBP are either insignificant or weakly significant. This means that volatility transmissions from other currencies to GBP did not significantly change after the referendum. Thus, it seems that after the referendum, GBP less affected other currencies whereas other currencies still remained the same impact on GBP. These results may appear to be contradictory of each other. However, they are actually compatible based on investors' migration mentioned above. If GBP is relatively weakened after the referendum, GBP as a single currency is likely to have less impact on other major currencies whereas other major currencies as a group are likely to maintain at least the same leverage on GBP.

Next, we look into extreme return movements between major foreign currencies using a bivariate copula approach. Because extreme returns in bad times have a negatively significant impact on the portfolio value, they should be separately taken into account and thus, investigating extreme return movements between major currencies is expected to provide important information in terms of portfolio risk management or diversification. Since we are interested in extreme return movements between major currencies during market downturns, we investigate how extreme returns move simultaneously using a bivariate copula.

Bivariate Archimedean copulas can be used to estimate extreme return distributions and probabilities between two variables by modelling tail dependence. As a matter of fact, a bivariate copula is the joint distribution function of uniform random variables. Klugman *et al*. (2008) show details about constructing different types of copulas. According to Sklar's theorem, for any joint distribution function (*Y),* a unique copula (*C*) exists and satisfies the following equation.

$$Y(x_1, x_2) = \mathrm{C}\big(Y_1(x_1), Y_2(x_2)\big) \tag{3}$$

Then, the Archimedean copula is defined as the bivariate joint distribution with marginal distributions as follows.

$$\mathrm{C}(\pi_1, \pi_2) = \mu^{-1}(\mu(\pi_1) + \mu(\pi_2)) \tag{4}$$

where $\mu(\pi)$ is a copula generator. The Clayton copula is one of asymmetric Archimedean copulas and is widely used for various applications. The Clayton copula has greater dependence weight to the negative tail of the distribution and thus, it appears to be an appropriate model for our purpose. The Clayton copula is defined as follows.

$$C(\pi_1, \pi_2) = Max\left[(\pi_1^{-\theta} + \pi_2^{-\theta} - 1)^{-1/\theta}, 0\right] \tag{5}$$

where $\mu(\pi) = (-1/\theta)\left(1 - \pi^{-\theta}\right)$ and θ is a dependence parameter. The dependence parameter of the Clayton copula is typically associated with Kendall's tau (T) that is a well-known rank correlation coefficient.

$$T = \theta/(2 + \theta) \tag{6}$$

Equation (6) provides the mathematical link between the dependence parameter of the Clayton copula and Kendall's tau. Based on Equation (5) and Equation (6), we estimate the likelihood of extreme return movements between major currencies. Table 3 shows copula probabilities that two currencies' extreme returns fall within their lowest nth percentiles simultaneously. Overall, all copula probabilities that currency pairs fall within their lowest nth percentiles simultaneously decrease during the post-crisis period except for (EUR, CAD) and (GBP, CAD) probabilities. This confirms that extreme return movements between major currencies tend to be weakened during the post-crisis period. This would be associated with hedging or policy changes made after the financial crisis.

However, extreme returns on (GBP, CAD) are more strongly tied during the post-crisis period (e.g., their copular probability for the lowest 10th P increases from 4.0% to 5.1%). Also, extreme returns on three European currency pairs – (EUR, CHF), (EUR, GBP), and (GBP, CHF) – are most simultaneously tied across both periods. This seems to be attributable to geographical dependence rather than market fundamentals because these five major currencies are most actively traded in the currency market. Similarly, extreme returns on currency pairs with JPY or CAD appear to be relatively less tied.

Table 3. Copula Probabilities

Bivariate currencies	Lowest 10th P	Lowest 5th P	Lowest 1th P
Panel A: Pre-financial crisis from January 3, 2002 to October 9, 2007			
(EUR, GBP)	0.075593	0.037775	0.007554
(EUR, JPY)	0.056430	0.027727	0.005480
(EUR, CAD)	0.049494	0.023897	0.004637
(EUR, CHF)	0.091003	0.045502	0.009100
(GBP, JPY)	0.050202	0.024292	0.004726
(GBP, CAD)	0.040148	0.018620	0.003423
(GBP, CHF)	0.074087	0.037012	0.007401
(JPY, CAD)	0.030850	0.013336	0.002181
(JPY, CHF)	0.060067	0.029696	0.005900
(CAD, CHF)	0.045562	0.021689	0.004136
Panel B: Post-financial crisis from October 10, 2007 to December 30, 2016			
(EUR, GBP)	0.062199	0.030836	0.006139
(EUR, JPY)	0.031659	0.013794	0.002288
(EUR, CAD)	0.050345	0.024371	0.004743
(EUR, CHF)	0.081288	0.040642	0.008128
(GBP, JPY)	0.017817	0.006220	0.000645
(GBP, CAD)	0.051290	0.024897	0.004860
(GBP, CHF)	0.051687	0.025118	0.004909
(JPY, CAD)	0.008465	0.001874	0.000049
(JPY, CHF)	0.045458	0.021630	0.004122
(CAD, CHF)	0.038979	0.017955	0.003267

Note: The lowest n^{th} P is the probability that both currencies' returns fall within their lowest n^{th} percentiles simultaneously.

4. Conclusion

We investigate volatility spillovers and extreme return movements between five major foreign currencies: EUR; GBP; JPY; CAD; CHF. Despite the fact that the 2007 Global Financial Crisis had a significant impact on financial markets, there have been few studies that examine volatility spillovers and extreme returns in major foreign currency markets with a focus on the 2007 Global Financial Crisis. Using the AR-GARCH model with exogeneous variables and the bivariate copula, we show how volatility spillovers and extreme return movements between major foreign currencies vary across the pre- and the post-crisis periods. Also, we consider the effect of the 2016 U.K. referendum known as Brexit on the British pound.

First, we find that volatility spillovers between major currencies become more significant during the post-crisis period. In particular, CAD shows the most significant change in volatility spillovers across the pre- and the post-crisis periods. Second, while volatility spillovers from GBP to other currencies are weakened after the referendum, those from other currencies to GBP remain the same without regard to the referendum. This would be explained by investors' migration from GBP to other major currencies after the referendum. If GBP is relatively weakened after the referendum, GBP as a single currency is likely to have less effect on other major currencies whereas other major currencies as a group are likely to maintain at least the same effect on GBP. Third, extreme return movements between major currencies tend to be weakened during the post-crisis period. This would be related to hedging or policy changes made after the financial crisis. Also, extreme returns on three European currencies tend to be more simultaneously tied together than those on JPY or CAD. This seems to be caused by geographical dependence rather than market fundamentals because these five major currencies are most actively traded in the currency market. Our results are expected to provide critical information to not only portfolio managers and investors but also policy makers.

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