Faculty of
Business
and Law

Working Papers in Economics & Finance
No. 2023-03

The Transmission Mechanism of Stress in the International Banking System

Lilian Muchimba, University of Portsmouth

Alexis Stenfors, University of Portsmouth

Portsmouth Business School
https://www.port.ac.uk/about-us/structure-and-governance/organisational-structure/our-academic-structure/faculty-of-business-and-law/portsmouth-business-school

The Transmission Mechanism of Stress in the International Banking System

Lilian Muchimba and Alexis Stenfors

Lilian Muchimba, University of Portsmouth, School of Accounting Economics and Finance, Richmond Building, Portland Street, Portsmouth PO1 3DE, UK, Email: lilian.muchimba@port.ac.uk (corresponding author)

Alexis Stenfors, University of Portsmouth, School of Accounting Economics and Finance, Richmond Building, Portland Street, Portsmouth PO1 3DE, UK, Email: alexis.stenfors@port.ac.uk

23 March 2023

***Abstract*:** Significant and volatile deviations from the covered interest parity (CIP) are indicators of stress in the international banking system. This paper uses a TVP-VAR model to investigate the dynamic connectedness and spillovers of such stress between the US, the UK, Japan and the Eurozone from 4 July 2006 to 9 June 2022. To do so, we use daily price data on cross-currency basis swaps (CRSs), typically used to trade and express CIP deviations for maturities of 1 year and beyond. We also incorporate a yield curve dimension by including prices representative of the short-term (1Y), medium-term (5Y) and long-term (10Y) to obtain a more nuanced picture of the role of market expectations. Our findings suggest that overall connectedness is highly event-dependent and peaks during periods of high volatility and market stress. However, the transmission mechanism across banking systems and yield curve maturities has evolved considerably over time, which has significant implications for policies attempting to mitigate future crises.

***Keywords*:** Banks, CIP deviations, Cross-currency basis swaps, Dynamic connectedness, TVP-VAR, Yield curves

JEL Classification Numbers : C32, C5, F3, G15

1. Introduction

Increased internationalisation of the global financial system, and particularly the banking system, has resulted in more interconnected financial markets. This development has influenced the speed, magnitude and direction of how stress and shocks are transmitted within the international financial architecture via the foreign exchange and money markets. Therefore, it is critical to understand the extent of interconnectedness and spillover of stress from one market to another. In this paper, we do so through the lens of the covered interest parity (CIP).

The CIP is one of the most important equations in international economics and finance. Borio et al. (2016) go so far as to classify the CIP as a "physical law in international finance". The equation elegantly shows how arbitrage activities ensure that the interest rate differential between two countries is immediately reflected in the foreign exchange (FX) market prices. A deviation of the CIP is an indicator of stress in the financial system. However, since the financial crisis of 2007-08, the CIP has rarely held. The CIP deviations are associated with various reasons in the literature ranging from the USD funding shortages (Baba, Packer and Nagano, 2008), differences in counterparty risks (Baba and Packer, 2009), and absence of capital required to exploit the arbitrage opportunities to zero (Ivashina et al., 2015). This has prompted the equation to evolve from an arbitrage condition to a benchmark or indicator of friction. Indeed, large and violent CIP deviations signify stress in the international banking system.

It is therefore critical to assess the extent of connectedness and spillover of stress across the international financial system. In this paper, through the lens of CIP deviations, we use a TVP-VAR model to investigate the dynamic connectedness and spillovers between financial systems We study the three major currencies (EUR, JPY and GBP) against USD from 4 July 2006 to 9 June 2022. To do so, we use daily price data on cross-currency basis swaps (CRSs), typically used to trade and express CIP deviations for maturities of 1 year and beyond. We also incorporate a yield curve dimension by including prices representative of the short-term (1Y), medium-term (5Y) and long-term (10Y) – to obtain a more nuanced picture of the role of market expectations.

Our findings show that the connectedness of CRSs is time-varying and elevated during periods of market stress. There is evidence of spillovers across CRSs, which become net transmitters when market stress is high and become net receivers in calm periods. From a maturity perspective, the transmission of shocks across the CRS yield curve shows that the 5Y segment spillovers to the 10Y segment for all CRSs. There are mixed results between 1Y and 5Y across currency bases. From a cross-currency perspective, the USD/EUR predominantly plays a net transmitting role to other cross-currency bases (USD/GBP and USD/JPY). This is sensible, as noted by Chatziantoniou et al. (2020), bases of banking sectors with significant banking operations tend to be net transmitters of shocks during periods of market volatility. Further, the USD/JPY assumed a net transmitting role during 2007-08 and the Covid-19 crisis. On the other hand, compared to the other cross-currency bases, the USD/GBP CRS was more or less muted except during the 2007-08 global financial crisis and assumed a predominantly net-receiving role. Overall, we document that the source, direction and magnitude of the transmission of CRS shocks appears to be highly unpredictable.

The remainder of the paper is organised as follows. Section 2 provides the technical exposition of the CIP before discussing the cross-currency basis deviations in Section 3. The data description and empirical methodology are provided in Section 4. The empirical results are discussed in Section 5. Finally, Section 6 provides a conclusion of the study and the policy implications.

2. A Technical Exposition of the CIP

The CIP is one of the most important equations in international economics and finance. It is a simple and logical formula, which states that FX swap[1], and consequently FX forward, prices should reflect the interest differential between two currencies. Otherwise, arbitrage would be possible. Formally, the CIP can be expressed as:

$$e^{ti_t^B} = e^{ti_t^C} \frac{S^{BC}}{F_t^{BC}} \quad (1)$$

---

[1] FX swaps, rather than FX forwards, are traded in the interbank market. An FX swap is a combination of an FX spot deal and an FX forward deal done simultaneously but in the opposite direction. Mathematically, then, an FX forward is a combination of an FX swap and an FX spot.

where i_t^B and i_t^C are the continuously compounded interest rates for currency B (base currency) and C (counter currency) for maturity t. $S^{B/C}$ and $F_t^{B/C}$ represent the FX spot and FX forward rates.

Suppose an arbitrageur borrows a specific amount in currency B for 3 months, immediately exchanges it to currency C at the prevailing FX spot rate, and then lends the converted amount in currency C for 3 months. The CIP states that it should not be possible to "close the circle" and lock in an immediate profit via a 3-month FX forward contract. If so, the CIP would not hold. Thus, such arbitrage logic is supposed to ensure that the prices continuously adjust to make sure that the equation holds and that the CIP deviation remains at zero.

The continuously compounded forward premium, ρ_t, equates to the interest rate differential of the two currencies in logs:

$$\rho_t \equiv \frac{1}{t}(F_t^{BC} - S^{BC}) = i_t^C - i_i^B \tag{2}$$

However, as this paper explores actual deviations from this parity condition, let us immediately add a new component to Equation 1: the *cross-currency basis,* x_t. The cross-currency basis is essentially the CIP deviation between two currency pairs for maturity *t*:

$$e^{ti_t^B} = e^{ti_t^C + tx_t} \frac{S^{BC}}{F_t^{BC}} \tag{3}$$

The expression of the cross-currency basis in log terms becomes:

$$x_t = i_t^B - (i_t^C - \rho_t) \tag{4}$$

The four equations above refer to a particular money market maturity t. In theory, this could be any maturity of 1 year or shorter. Conventionally, the 3-month maturity is used to express the short-term CIP deviation or cross-currency basis. However, it is also possible to derive, say, the 3-month cross-currency basis starting in 3 months, 6 months or even further out in time. In order to derive cross-currency bases beyond 1 year, there needs to be a tradable cross-currency basis swap (CRS) market. This is because the liquidity in the FX swap market is dramatically lower for maturities beyond 1 year.

A CRS is a type of interest rate swap with floating rate coupons in two different currencies. Money market benchmarks (such as LIBOR) are used to determine the floating rate coupons. The price of a CRS is the cross-currency basis, x_t^{XCCY}, which is conceptually similar to a series of x_t – but typically with a longer contract maturity than 3 months. For instance, suppose that Bank A pays -10 in the USD/JPY 1-year CRS market for USD 100 million (JPY 10 billion, assuming a hypothetical USD/JPY FX rate of 100) and that the counterparty is Bank B. Bank A is borrowing JPY floating and lending USD floating and Bank B is doing the opposite. This means that every quarter for 1 year, Bank A is paying 3-month JPY LIBOR minus 10 bps to Bank B on JPY 10 billion. In return, Bank A receives 3-month USD LIBOR flat from Bank B on USD 100 million. Thus, the CRS price is expressed in terms of the premium or discount on the non-USD floating leg. In this example, '-10' is referred to as the 'cross-currency basis' or simply just the 'basis'.

In Equation 1, the short-term interest rates used were money market rates. However, in Equation 5 below, the longer-term (i.e. involving more than one "CIP coupon") CRS can be split into a longer-term zero-coupon fixed-fixed cross-currency swap and two fixed-for-floating longer-term interest rate swaps (i^{IRS}) in two currencies and opposite directions:

$$e^{ti_t^{IRS(B)}} = e^{ti_t^{IRS(C)}+tx_t^{XCCY}} \frac{S^{BC}}{F_t^{BC}} \tag{5}$$

The (longer-term) forward premium is then:

$$\rho_t \equiv \frac{1}{t}(F_t^{BC} - S^{BC}) = i_t^{IRS(C)} - x_t^{XCCY} - i_i^{IRS(B)} \tag{6}$$

3. Explaining CIP Deviations and Cross-Currency Basis Fluctuations

Borio et al. (2016) classify the CIP almost as a "physical law in international finance". This simple and widely used equation shows that that interest rate differentials between two currencies (in cash money markets) should be equal to the spot and forward rate differentials, otherwise arbitrageurs could a make risk-free profit. It is, therefore, not surprising that the bulk of the first and early set of literature relates to the CIP equation itself, which shows that the interest rate differential between two currencies should be reflected in the FX swap price (e.g. Keynes, 1923; Einzig, 1937).

However, the second set of literature emerged during and in the immediate aftermath of the Japanese banking crisis in the 1990s. The crisis resulted in substantial deviations of the CIP, and, from a cross-currency basis point of view, the episode can be seen as a prequel to the much more significant and long-lasting impact of the Great Recession. The Japanese banking crisis was crucial, though, because it revealed the influence of the perceived creditworthiness of banks on the parity condition. Recall Equation 2 in Section 2, where i_t^B denotes the term interest rate of the base currency, say the 3-month USD. Conventionally, a money market benchmark such as the London Interbank Offered Rate (LIBOR) is used as input in the equation – on the assumption that it is representable of the borrowing and lending of USD among banks of good standing for 3 months. However, the crisis forced Japanese banks (including very large ones) to pay more to borrow USD in the international money market. Consequently, the so-called 'Japan premium' that emerged became an expression of the extra premium Japanese banks had to pay to access funds in the interbank market compared to their non-Japanese peers. This premium soared during the crisis and became reflected in substantial CIP deviations for USD/JPY and other JPY-related currency pairs during the peak of the crisis. In essence, the CIP deviations and cross-currency bases reflected the extra "price" Japanese had to pay for swapping JPY (which they, in the worst case scenario, could access from the Bank or Japan) into USD via the FX swap or CRS market (Peek and Rosengren, 2000, 2001). At the time, Spiegel (2001) showed that the CIP deviation was inversely correlated with the strength and creditworthiness of the Japanese banks and the banking system as a whole.

After a few years, the Japan-related CIP deviations returned to zero. The parity condition held well until the financial crisis broke out in August 2007. After that, CIP deviations started to appear in various currencies, with the sharpest violations around the collapse of Lehman Brothers (see, for instance, Coffey et al., 2009; Genberg et al., 2011; Manchini-Griffoli et al., 2012). This triggered a third set of research agenda. The literature mainly focussed on the observation that the drivers not only consisted of perceived increased counterparty risk but, more importantly, funding liquidity risk – particularly in USD. It had become apparent that whereas the Japanese banking crisis was country-specific (involving Japan), the financial crisis of 2007-08 was global and more currency-specific (involving USD) (Stenfors, 2019). Global banks faced a shortage of US dollars, which caused substantial CIP deviations. This demand could not be met and was ultimately addressed through international central bank cooperation at an unprecedented scale. An FX swap network was established with the US Federal Reserve at the helm (Baba and Packer, 2009; McGuire and von Peter, 2012). By channelling US dollars to other central banks in the network, non-US banks could access US liquidity in a way that had not been possible before (nor had it been an option for Japanese banks during the Japanese banking crisis). The internationalisation of the global banking system was seen as an essential factor as an explanation of the evolution of the CIP from zero to an indicator of stress in the international banking system (Giannetti and Laeven, 2012; Stenfors, 2019). For instance, Iida et al. (2016) pointed out that frictions in the cross-currency basis swap markets might cause non-US banks to cut back on USD lending.

The European Sovereign Debt Crisis during 2010-12 resulted in renewed volatility in the cross-currency swap markets. Gradually, the persistent CIP deviations became referred to as the 'CIP puzzle'. Thus, in various ways, the fourth set of literature has come to terms with the observation that CIP deviations might be here to stay. A growing number of articles began to approach the issue, acknowledging that more fundamental factors might be at play. Indeed, a common theme with the vast majority of studies is that they each point to one or several factors causing substantial and long-lasting deviations. Borio et al. (2016), for instance, argue that the accumulated US dollar funding gaps held by other G10 banks are so systematic that the one-sided demand prevents the CIP deviations from being arbitraged away. Further, Ivashina et al. (2015) attributes the CIP deviations to the USD funding strains and absence of capital needed to exploit the arbitrage activities. Sushko et al. (2016) stress the combination of FX hedging demand and balance sheet constraints, whereas Iida et al. (2016) point towards the relevance of monetary policy divergence in a low interest rate environment. Attempting to decompose and quantify various factors impacting the CIP deviations becomes a logical next step (see Du et al., 2018).

Stenfors (2014ab, 2018, 2019), by contrast, argues that the CIP deviations and CRS bases should be seen as prices rather than exceptions or anomalies. This approach is also taken by Chatziantoniou et al. (2020), who use a TVP-VAR framework to study contagion across short-term CRSs across G10 countries. Without attempting to explain the causes behind the CIP deviations, the authors document that connectedness and contagion is event-dependent and closely related to crises. Furthermore, currencies associated with large banking systems tend to be transmitters of shocks via the CRS markets, whereas safe-haven and peripheral currencies assume shock-receiving roles.

4. Data and Methodology

We focus on the three most widely traded currencies against USD, namely EUR, JPY and GBP, and cover the period from 4 July 2006 to 9 June 2022. We use daily (last) end-of-day CRS prices submitted by ICAP (one of the leading CRS interdealer brokers) to Bloomberg. In contrast to Chatziantoniou et al. (2020), we include a yield curve element in the analytical framework. The maturities chosen are 1, 5 and 10 years, representing the short-, medium- and long-term CRS market. As Stenfors et al. (2022) noted, the currency and maturity dimensions are crucial in tracing connectedness in the global fixed income and other interest rate markets. Per market convention, the floating rates used are 3-month USD LIBOR, EUR Euro Interbank Offered Rate (EURIBOR), JPY LIBOR and GBP LIBOR.

To measure the dynamic connectedness of variables in a network, most models are based on work by Diebold and Yilmaz (2009, 2012, 2014). The Diebold and Yilmaz model, based on the extensively used vector autoregressive model (VAR) developed by Sims (1980), allows for both static and dynamic analysis of a system (network) of variables. This paper employs the Time-Varying Parameter Vector Autoregression (TVP-VAR) model developed by Antonakakis (2020), to measure the extent and dynamic connectedness of CRSs of three currencies, namely EUR, JPY and GBP against USD. The analysis is done for three maturities: 1Y, 5Y and 10Y. This model has three significant advantages. First, results are not affected by the size of the rolling window. Second, data outliers do not affect outcomes. Third, observations are not excluded when moving across windows (Chatziantoniou et al., 2020). The TVP-VAR approach uses the widely used variance decompositions, which allow for the aggregation of spillover effects across instruments, thereby extracting valuable information into a single spillover measure. The following TVP-VAR model is estimated as suggested by the Bayesian Information Criteria (BIC) for the three currencies and maturity categories:

$$Z_t = B_t Z_{t-1} + u_t \quad u_t \sim N(0, S_t) \tag{7}$$

$$vec(B_t) = vec(B_{t-1}) + v_t \quad v_t \sim N(0, R_t) \tag{8}$$

Where Z_t, Z_{t-1} and u_t are kx1 dimensional vectors, representing all variables (EUR, JPY and GBP) in three maturity categories (1Y, 5Y and 10Y) in t, t-1, and the respective error term. B_t and S_t are kXk dimensional matrices, $vec(B_t)$ and v_t are k^2X1 dimensional vectors and R_t is a K^2xK^2 dimensional matrix.

The H-step ahead (scaled) generalized forecast error variance decomposition (GFEVD) by Koop et al. (1996) and Pesaran and Shin (1998) are calculated. Importantly, the GFEVD is completely invariant to the order of variables contrary to the orthogonalized forecast error variance decomposition (Diebold and Yilmaz, 2009). The representation is based on Wold representation theorem, and therefore the estimated TVP-VAR model is transformed into a TVP-VMA process:

$$z_t = \sum_{i=1}^{p} B_{it} z_{t-i} + u_t = \sum_{j=0}^{\infty} A_{jt} u_{t-j} \tag{9}$$

The (scaled) GFEVD normalises the unscaled GFEVD, $\emptyset_{ij,t}^{g}(H)$ so that each row sums to 1. In this regard, $\widetilde{\emptyset_{ij,t}^{g}}(H)$ below represents the influence on variable i's forecast error variance from variable j, also called pairwise directional connectedness from j to i.

$$\emptyset_{ij,t}^{g}(H) = \frac{S_{ii,j}^{-1} \sum_{t=1}^{H-1} (i'_i A_t S_t i_j)^2}{\sum_{j-1}^{k} \sum_{t=1}^{H-1} (i_i A_t S_t A_t^{\prime i_i})} \tag{10}$$

$$\widetilde{\emptyset_{ij,t}^{g}}(H) = \frac{\emptyset_{ij,t}^{g}(H)}{\sum_{j=1}^{k} \emptyset_{ij,t}^{g}(H)} \tag{11}$$

Where $\sum_{j=1}^{k} \widetilde{\emptyset_{ij,t}^{g}}(H) = 1, \sum_{j=1}^{k} \widetilde{\emptyset_{ij,t}^{g}}(H) = k$ and i is the selection vector with unity on the i^{th} position and zero, otherwise. Then the GFEVD is computed as per Diebold and Yilmaz (2012, 2014) which allows us to calculate the following connectedness measures:

$$TO_{jt} = \sum_{i=1, i \neq j}^{k} \widetilde{\emptyset}_{ij,t}^{g}(H) \tag{12}$$

$\widetilde{\emptyset}^{g}_{ij,t}$ is the impact of a shock on i resulting from a shock on variable j, The $TO_{jt} = \sum_{i=1,i\neq j}^{k} \widetilde{\emptyset}^{g}_{ij,t}(H)$ is also referred as total directional connectedness represents the combined impact a shock on variable j has on all other variables.

$$FROM_{jt} = \sum_{i=1,i\neq j}^{k} \widetilde{\emptyset}^{g}_{ij,t}(H) \tag{13}$$

$FROM_{jt} = \sum_{i=1,i\neq j}^{k} \widetilde{\emptyset}^{g}_{ij,t}(H)$ also referred to the total directional connectedness from others shows the combined impact of a shock on all the other variables have on variable j. To obtain information as to which variable is a net transmitter or receiver. The following net total connectedness index is calculated:

$$NET_{jt} = TO_{jt} - FROM_{jt} \tag{14}$$

If $NET_{jt} > 0$, then the variable is a net transmitter of shocks, otherwise ($NET_{jt} < 0$), the variable is the net recipient of shocks.

$$TCI_t = k^{-1} \sum_{j=1}^{k} TO_{jt} \equiv k^{-1} \sum_{j=1}^{k} FROM_{jt} \tag{15}$$

TCI_t (Total connectedness index) represents total forecast error variance in one cross-currency basis explained by the shocks of all the other variables. The range for the TCI is [0%, 100%]. If it is 100%, it means that on average, all variables in the network explain 100% of the variation of given variable. Therefore, interconnectedness of the network is high and stress in one market segment (CRS) is more likely to be transmitted to other variables in the network. A TCI of 0% means that variables are independent of each other and do not react to shocks of all other variables in the network. All variables above offer information on an aggregated basis. To get an indication of the bidirectional relationships between variables the Net Pairwise Directional Connectedness is calculated below:

$$NPDC_{ij,t} = \widetilde{\emptyset}_{ij,t}(H) - \widetilde{\emptyset}_{ji,t} \tag{16}$$

$NPDC_{ij,t}$ indicates the direction of shocks between two variables, j and i. That is, which variable is driving the other. If $NPDC_{ij,t} > 0$, then variable i is driving j , and if $NPDC_{ij,t} < 0$, then variable i is being driven by variable j.

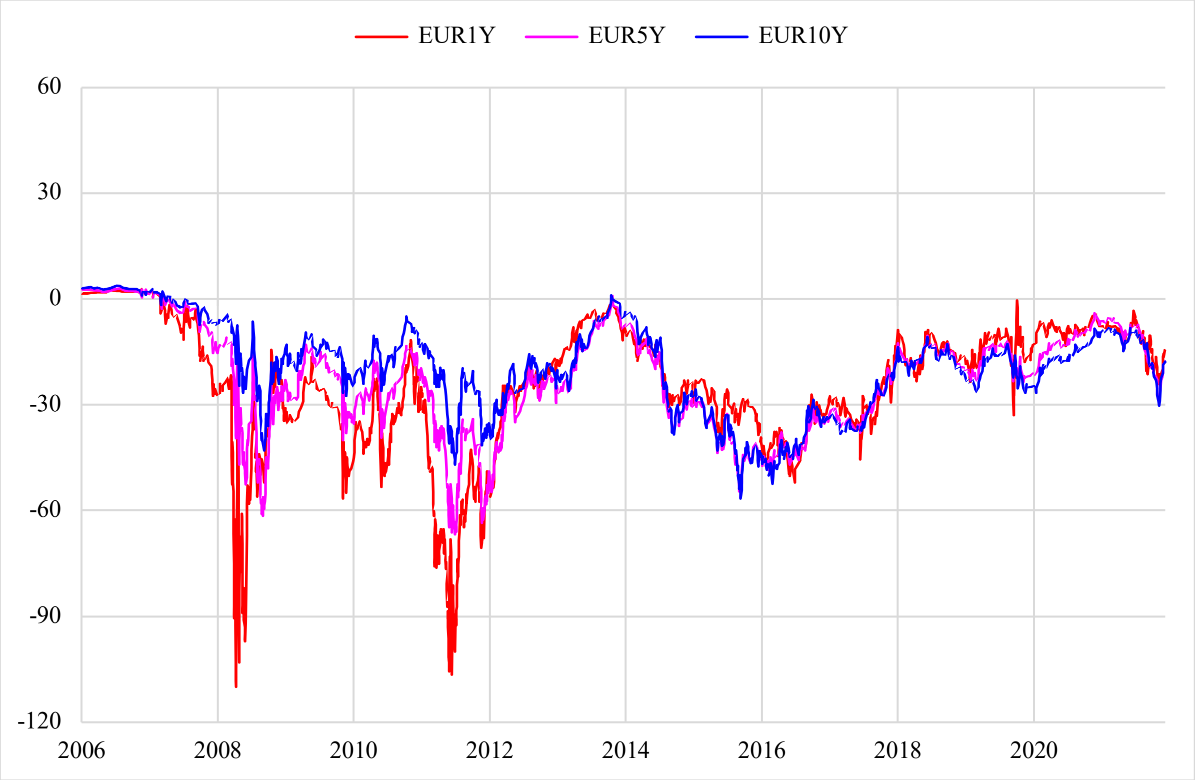
5. Empirical Results

5.1. Summary Statistics

Figure 1 below shows the 1Y, 5Y and 10Y cross-currency basis swaps for the USD/EUR, USD/JPY and USD/GBP. A CRS value of zero essentially indicates that the CIP condition holds and/or is expected to hold for the maturity in question. As can be seen, before the financial crisis of 2007-08, all CRSs traded close to zero – demonstrating that the CIP condition held pretty well up until then. However, the global USD funding challenges from August 2007 resulted in substantial CIP deviations during and after the crisis. A combination of elevated counterparty risk and funding liquidity risk resulted in market participants decreasing their direct cash lending – spurring global USD funding shortages. Consequently, market participants, and particularly banks with large-scale operations abroad, resorted to the FX swap and CRS markets to access USD funding. As a result, as outlined in Section 2, the basis turned sharply negative against the USD for a range of currency pairs.

As shown in Figure 1a, the EUR1Y CRS widened significantly, reaching -110 basis points on 9 October 2008. This indicated that a premium of 110 basis points was required to swap 3-month floating EUR in order to borrow 3-month floating USD for 1 year. While this basis reduced following the establishment of FX swap lines across the globe, there was a re-emergence of strains in the CRS market following the sovereign debt concerns in the Euro area. Resultantly, the basis widened again (European Central Bank [ECB], 2011).

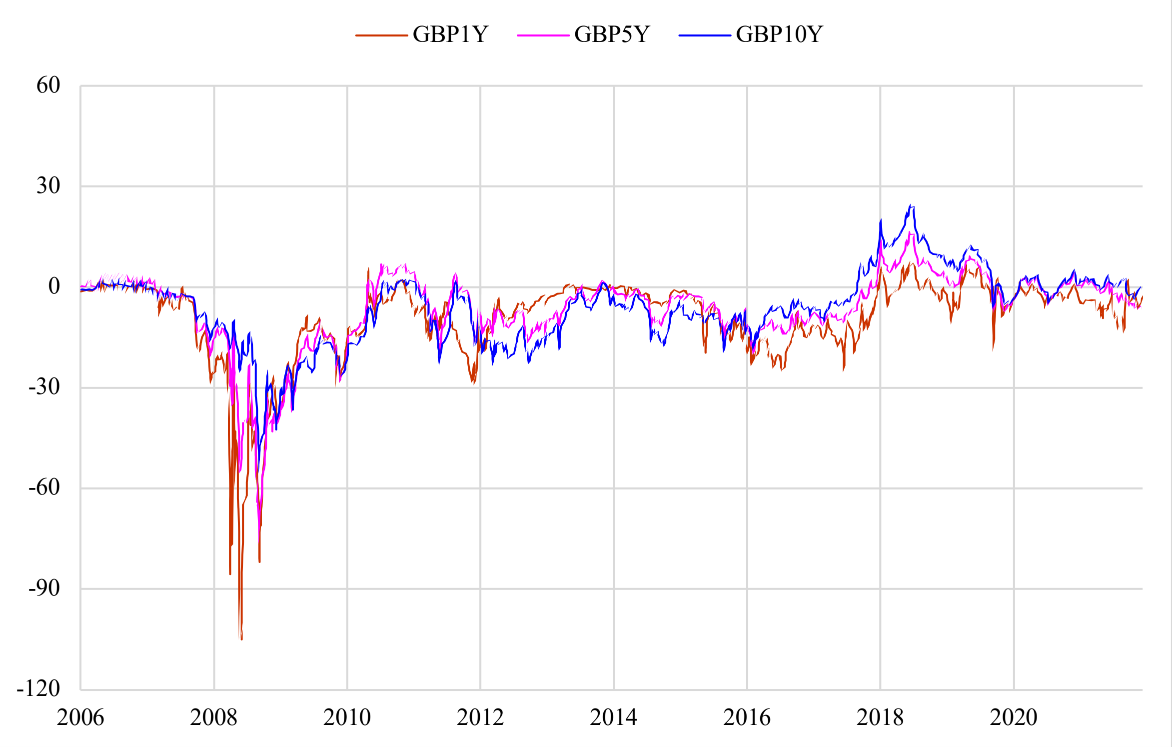
Figure 1a: USD/EUR Cross-Currency Basis Swaps



Source: Bloomberg. Note: 3M USD LIBOR flat against 3M EUR EURIBOR.

As depicted in Figure 1b below, the USD/GBP CRSs also turned sharply negative during the global financial crisis. Since then, however, the swings have been considerably more muted than for USD/EUR. Notably, the CIP for this currency pair more or less held during 2013-15.

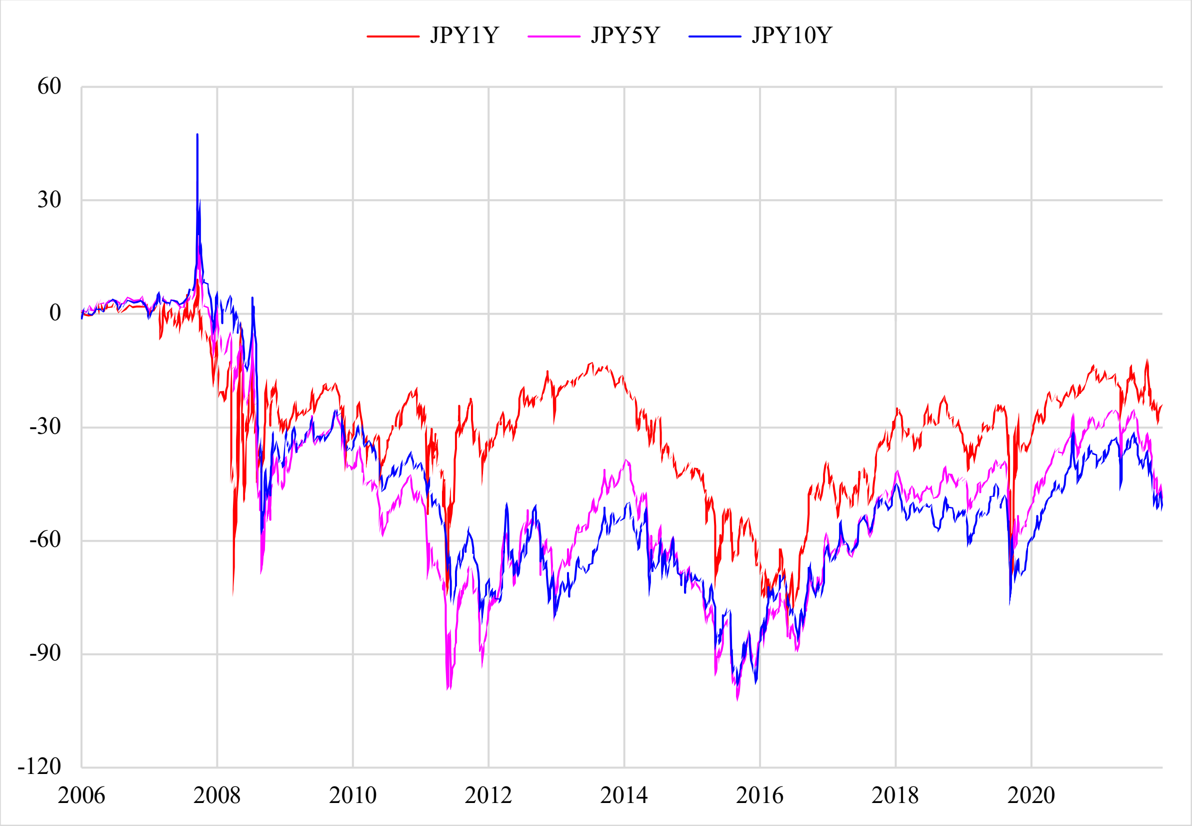
Figure 1b: USD/GBP Cross-Currency Basis Swaps



Source: Bloomberg. Note: 3M USD LIBOR flat against 3M GBP LIBOR.

The USD/JPY CRSs were also negative during the financial crisis of 2007-08 (see Figure 1c). As mentioned, Japan was already experiencing CIP deviations during the banking crisis of the 1990s. During that time, Japanese banks were perceived as less creditworthy and therefore found it difficult to access unsecured funds, including foreign currency funding from domestic sources. Japanese banks needed foreign currency funding, particularly USD, to support their investments abroad. Consequently, they resorted to the cross-basis swap market for their liquidity needs. To address the crisis (eliminate the Japanese Premium), the Bank of Japan injected USD liquidity and instituted other reforms. Resultantly, the CIP deviation dissipated in the late 1990s. However, these deviations resurged following the collapse of the Lehman Brothers in 2008. Strikingly, USD/JPY CRSs have remained sharply negative since – to a large degree as a result of the expansion of Japanese banks abroad (Stenfors, 2019).

Figure 1c: USD/JPY Cross-Currency Basis Swaps



Source: Bloomberg. Note: 3M USD LIBOR flat against 3M JPY LIBOR.

Table 1 below shows the summary statistics for cross-currency basis swaps (EUR, JPY and GBP) against the USD in three maturities (1Y, 5Y and 10Y) for the period 4 July 2006 to 9 June 2022. The statistics show that the short-end (1Y) maturity segment of CRSs has the highest variability in the period under review. Before proceeding to the connectedness analysis, in line with Elliot et al. (2016), unit root tests are done using the Elliot, Rothenberg and Stock (ERS). The ERS shows that all instruments (EUR and JPY) but the GBP are non-stationary at 1% and 5% levels of significance. All series are differenced once to avoid spurious regression and obtain percentage changes. Further, the skewness and kurtosis in Table 1 indicate that the series are not normally distributed (D'Agostino, 1970; Jarque and Bera 1980; Anscombe and Glynn, 1983). The Q(20) and Q2(20), which are the weighted Ljung-Box statistic tests for serial correlation in returns and squared series, show evidence of autocorrelation in the series (Fisher and Gallagher, 2012). The characteristics of the data series show that the TVP-VAR model is an appropriate economic analysis framework.

Table 1: Summary Statistics

	Mean	Variance	Skewness	Ex. Kurtosis	Jarque Bera	ERS	Q(10)	Q2(10)	Obs.
EUR1Y	0.0040	3.8720	-0.51***	42.97***	308607.75***	-32.23***	402.47***	3497.97***	4009
EUR5Y	0.0050	1.1330	0.04	19.62***	64273.57***	-28.93***	215.51***	1030.27***	4009
EUR10Y	0.0050	0.7410	0.03	9.37***	14659.07***	-26.65***	143.01***	491.80***	4009
JPY1Y	0.0060	3.3750	0.15***	30.98***	160294.09***	-26.85***	176.00***	1049.18***	4009
JPY5Y	0.0130	1.6240	0.04	29.53***	145628.32***	-27.71***	59.42***	520.94***	4009
JPY10Y	0.0130	1.5640	0.15***	46.56***	362193.19***	-8.24***	45.81***	1103.37***	4009
GBP1Y	0.0000	2.4180	-0.15***	81.61***	1112547.17***	-28.23***	341.02***	1468.63***	4009
GBP5Y	0.0020	0.7900	-0.29***	23.95***	95905.39***	-26.72***	143.82***	508.03***	4009
GBP10Y	0.0000	0.5860	-0.31***	13.58***	30849.30***	-27.04***	90.04***	514.61***	4009

Source: Bloomberg and author's calculations. Notes: obs. is the number of observations. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Skewness and Ex. Kurtosis are measured according to D'Agostino (1970) and Anscombe and Glynn (1983). Jarque and is the test for Normality Bera (Jarque and Bera 1980). ERS is the Elliot, Rothenberg and Stock (ERS) unit root tests for stationarity (Elliot et al. 1996). The Q(20) and Q2(20) are the weighted Ljung-Box statistics for serial correlation in the returns and squared series (Fisher and Gallagher, 2012), respectively.

5.2. Static Connectedness Measures

This section explains the connectedness indices in detail before moving on to the results. Table 2 and Figure 2 below present the static connectedness measures of the CRSs (EUR, GBP and JPY against the USD) for the 1Y, 5Y and 10Y maturity categories. Table 2 displays the average connectedness measures, namely, TCI, on-diagonal, and off-diagonal elements, "TO", "FROM", "NET", and NPDC. The TCI measures the degree of the connectedness of variables in a network. The TCI is the total forecast error variance in one cross-currency basis explained by the shocks of all the other variables. The range for the TCI is [0%, 100%]. A TCI of 0% means that the variables in question are unrelated and thus independent of each other. This implies that a variable in the system does not react to shocks of all other variables in the network. On the other hand, a value of 100% means that the network of variables is highly interconnected. A measure of or close to 100% implies that a shock in one variable will spillover to other variables in the network. From a CIP perspective, a high TCI is a possible indication that dislocations (market stress measured by the CIP deviation) in one market segment are likely to spill over to others. A high TCI indicates that a variable is susceptible/vulnerable to stress across each cross-currency basis yield curve and developments in other cross-currency bases (international markets).

Table 2: Average Connectedness Measures

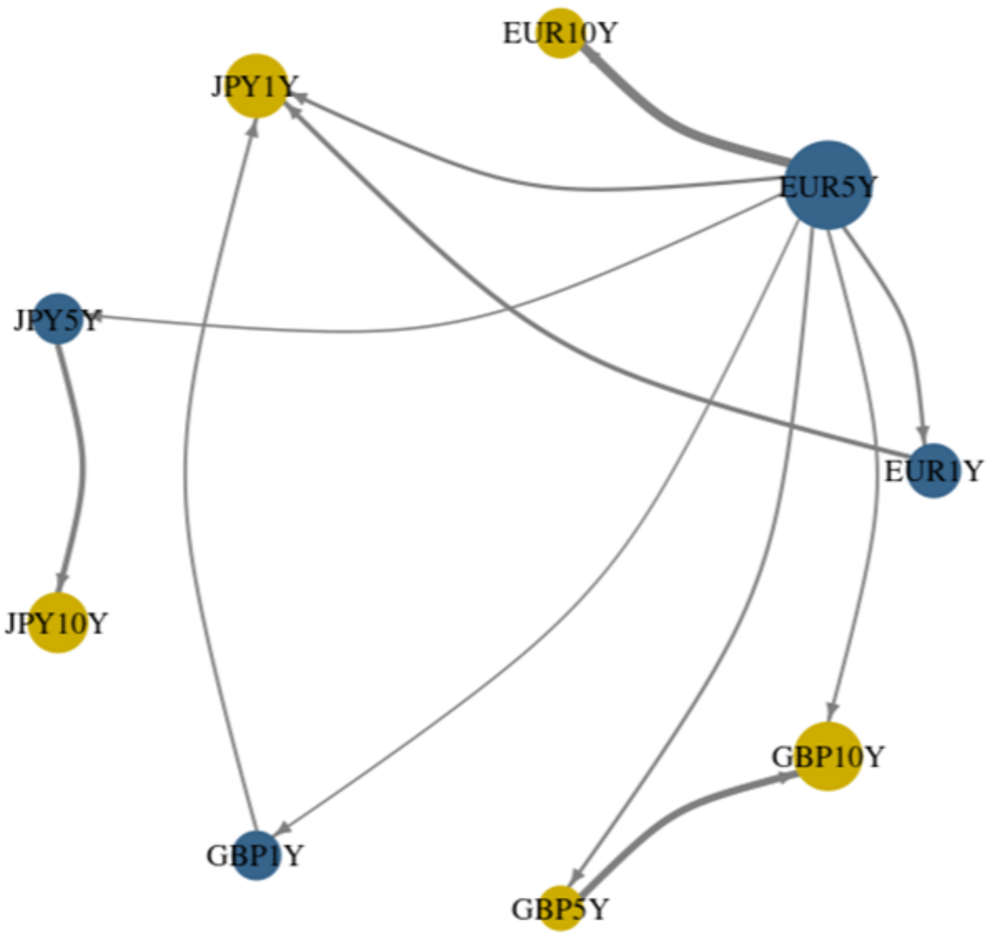
	EUR1Y	EUR5Y	EUR10Y	JPY1Y	JPY5Y	JPY10Y	GBP1Y	GBP5Y	GBP10Y	FROM
EUR1Y	42.52	16.41	8.68	7.85	3.75	2.16	11.68	4.56	2.4	57.48
EUR5Y	13.95	38.14	26.43	3.55	3.69	2.21	3.94	4.79	3.31	61.86
EUR10Y	9.31	32.29	40.61	2.58	2.69	1.8	2.69	4.45	3.58	59.39
JPY1Y	10.85	5.93	3.27	44.81	14.25	8.51	8.22	2.61	1.55	55.19
JPY5Y	4.4	5.29	3.08	13.37	41.82	26.17	2.62	1.84	1.4	58.18
JPY10Y	2.55	3.44	2.42	9	29.75	47.06	2.38	1.9	1.52	52.94
GBP1Y	11.56	5.51	3.16	6.19	2.68	2.16	49.55	12.38	6.81	50.45
GBP5Y	5.56	6.97	5.3	2.45	2.08	1.67	13.07	40.34	22.56	59.66
GBP10Y	3.39	5.31	4.85	1.86	1.77	1.5	7.8	27.12	46.4	53.6
TO	61.56	81.14	57.18	46.85	60.67	46.17	52.39	59.65	43.14	508.75
Inc.Own	104.08	119.28	97.78	91.67	102.49	93.23	101.95	99.99	89.54	TCI
NET	4.08	19.28	-2.22	-8.33	2.49	-6.77	1.95	-0.01	-10.46	56.53
NPT	6	8	6	2	5	0	5	3	1	

Source: Bloomberg and author's calculations. Note: NPT (net pairwise transmission) measures the average contribution of transmission of each variable in the bidirectional relationships with other variables, in the entire period.

The TCI (56.53%) in Table 2 means that 56.53% of the total forecast error variance in one cross-currency basis instrument can be explained by the shocks or innovations of all the others. Compared to other similar networks, this network is relatively more interconnected than the network of 1Y cross-currency basis swaps for all G10 currencies (TCI: 36.53%) revealed in the study by Chatziantoniou et al. (2020). The diagonal elements in Table 2 show that these instruments are highly influenced by their own shocks or innovations.

Decomposing the TCI into "TO" and "FROM" measures, the "TO" index measures the extent of transmission of shocks from each instrument to the entire network. On the other hand, the "FROM" measures the shocks on an aggregate basis that each instrument receives from the entire system of variables. Notable is the "TO" and "FROM" indicators show that the 5Y maturity category across all CRSs plays a role as both transmitters and receivers of shocks in the network. However, the "TO" and "FROM" measures do not show which instrument is a net transmitter or receiver of shocks. The "NET" indicator provides this information and shows that EUR1Y, EUR5Y, JPY5Y and GBP5Y are net transmitters of shocks in the network. The medium-term EUR CRS plays a considerably higher net transmission role relative to the others in the network. The remaining CRSs are net recipients of shocks. These results are consistent with Figure 2 below. While the "NET" shows variables play a dominant role in the whole network, the NPT shows, on average, the role of each variable in bidirectional relationships. It shows that the EUR CRSs, JPY5Y and GBP1Y are large drivers of shocks in bidirectional relationships.

Figure 2: Network of Cross-Currency Basis Swaps



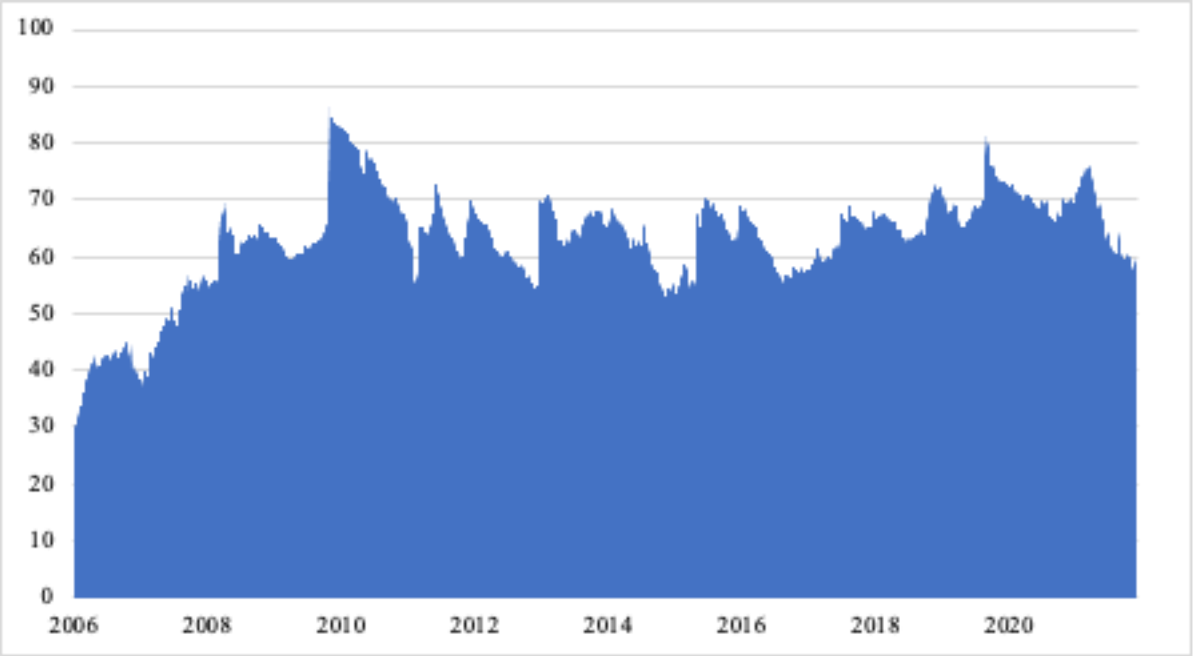
Notes: Blue [yellow] nodes represent net transmitter [net recipient] of shocks. Links are weighted by averaged net pairwise directional connectedness measures. The size of nodes represents weighted average net total directional connectedness. The network plot results are based on a TVP-VAR model with a lag length of order one (BIC) and a 10-step-ahead generalized forecast error variance decomposition.

Figure 2 presents a network using a graph considered a system of cross-currency basis swaps across maturity categories (nodes). The nodes (vertices) represent the variables, while the links (directed arrows) show the static pairwise directional connectedness. Blue nodes represent net transmitters, while the yellow nodes represent net recipients of shocks in the system. Links are weighted by averaged net pairwise directional connectedness measures. The thicker the node, the higher the influence the instrument has on the system of variables. The network plot results are based on a TVP-VAR model with a lag length of order one (BIC) and a 10-step-ahead generalized forecast error variance decomposition. Consistent with Table 2 above, Figure 2 shows that the EUR1Y, EUR5Y, JPY5Y and GBP1Y are net transmitters in the system, with the EUR5Y playing a more prominent role (demonstrated by the size of the node). The other instruments (EUR10Y, JPY1Y, JPY10Y, GBP5Y and GBP10Y) are net receivers of shocks in the system.

5.3. Dynamic Connectedness Measures

While the static connectedness measures presented above are useful, they do not show the evolution of the interrelations among variables over time. Figure 3 below covers this gap and shows the evolution of the connectedness of cross-currency basis swaps overtime.

Figure 3: Dynamic Total Connectedness

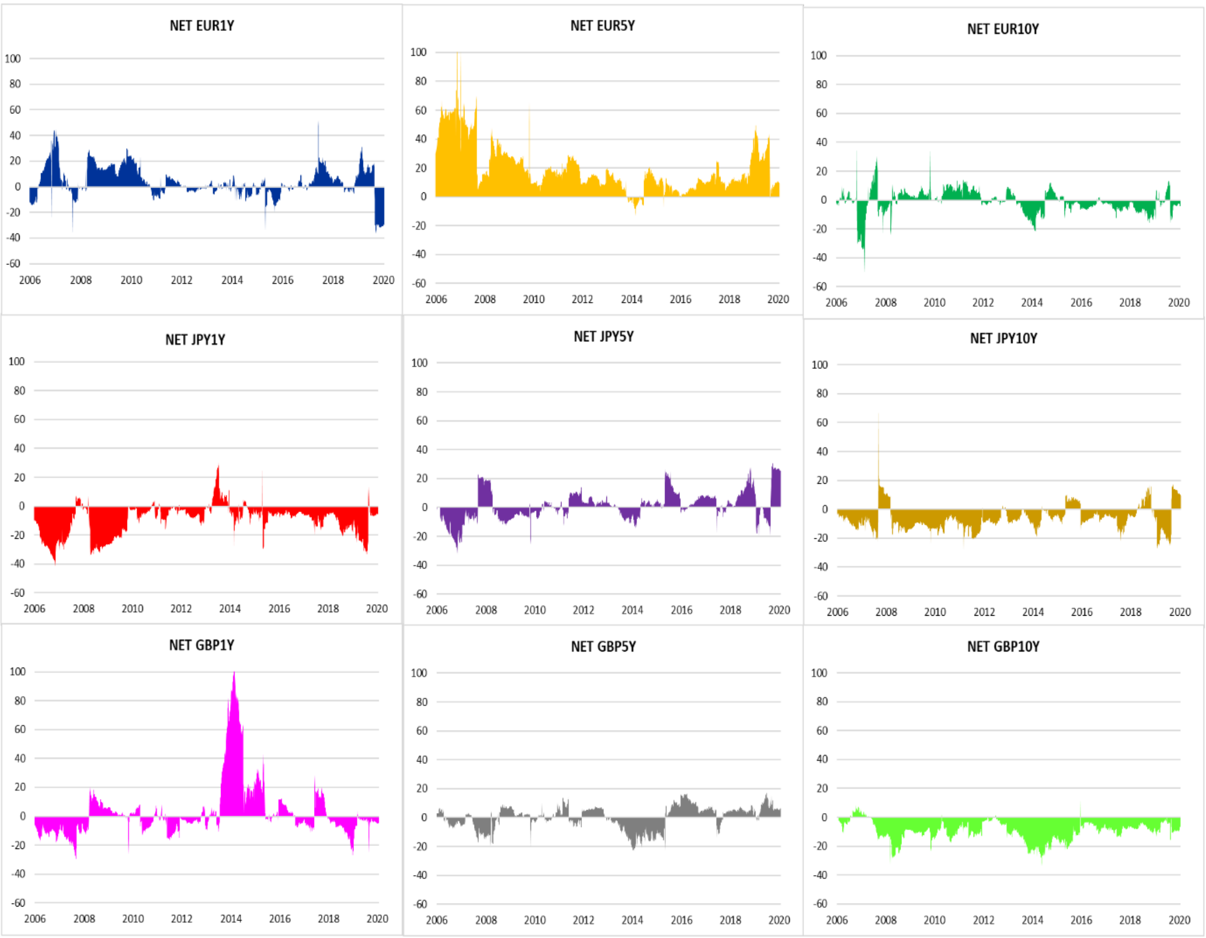


Consistent with documented literature (Chatziantoniou et al., 2020; 2021), connectedness is highly event dependent and high during periods of high volatility and market stress. Such periods are typically associated with weaker market confidence and higher risk premia. For example, before the financial crisis of 2007-08, the TCI index was rarely above 40%. Notably, this was a period when CIP deviations were small, and the CRS prices in this study fluctuated within a narrow band around zero. Thus, despite all nine variables gravitating towards zero, the “universe” of major CRS prices was only moderately connected. Notice, however, the significant jump in the overall level of connectedness from August 2007, with peaks coinciding with key market events. Important examples include Bear Sterns, the collapse of Lehman Brothers, the launch of the FX swap network, the European Sovereign Debt Crisis, the Money Market Mutual Fund (MMMF) reform, and the recent Covid-19 pandemic. As previously mentioned, during the financial crisis of 2007-08, the global dollar shortages contributed to the heightened credit and liquidity risks and increased premiums required to borrow dollars using other currencies in the CRS markets. During the European Sovereign Debt Crisis, the re-emergence of tensions in the funding markets led to a wider cross-currency basis. Recently, during the Covid-19 pandemic, the financial turbulence immediately resulted in a shortage of USD – thereby raising the cost of dollars in FX markets (Avdjiev et al., 2020).

5.4. Net Total Directional Connectedness

The TCI in Figure 3 above helps show the aggregate connectedness of the network of variables over time but does not show the transmission specifics of each variable. Figure 4 below shows the disaggregated information and the transmission of shocks evolution for each variable. If the value is positive, the instrument is a net transmitter (primary driver) of shocks to others in the system. On the other hand, if the value is negative, a variable is a receiver of shocks and has no or limited influence on the other variables in the system.

Figure 4: Net Total Directional Connectedness



In line with the static analysis above, Figure 4 shows that while all instruments assume both shock transmission and absorption roles over time, the short-end of the USD/EUR cross-currency basis assumed a net receiving role up to mid-2007, before becoming a net transmitter during the global financial crisis and the start of the European Sovereign Debt Crisis. The medium-term (EUR5Y) predominantly assumed a net transmission role for most of the period. On the other hand, the role of the long-end part of the curve (EUR10Y) has been mixed.

The short-end (1Y) and long-end (10Y) USD/JPY cross-currency bases assumed a net receiving role for most of the period, whereas the medium-term (5Y) was mixed. With regards to USD/GBP, the long-end (10Y) and medium-term assumed a net-receiving role, whereas GBP5Y was a moderate transmitter of shocks from 2015 onwards. Notably, GBP1Y was a prominent transmitter of shocks to the network during 2013-15.

Thus, at this stage, two key observations are notable. First, the 10-year maturities for all three currency pairs have tended to be receivers of shocks from the universe of CRSs in this study.

This is, to a large degree, logical when referring back to the mathematical exposition of the CIP in Section 2. CRS can be seen as a combination of current and expected future CIP deviations. Violent swings in the CIP, therefore, have a relatively more noticeable impact on the short-term than the long-term basis curve. Long-term CRS prices are not only driven by expected future CIP deviations. The asset swap market also causes swings in supply and demand which may affect CRS prices. However, from Figure 4, it appears as if long-term expectations and the asset swap market are comparatively minor transmitters of shocks to the CRS market as a whole.

Second, the net total dynamic connectedness measures show that significant shock transmission occurs when the total connectedness is very low or extremely high. Illustrative examples include the period before August 2007, when all CRSs traded close to zero (see Figures 1a, 1b and 1c). However, another striking episode includes a lengthy period between 2013 and 2015, when the CIP deviation was minimal for USD/GBP, and GBP1Y traded close to zero - despite swings in CRSs for longer maturities and, in particular, other currency pairs. At the other end of the spectrum, we also find episodes characterised by significant stress in the international banking system in the form of the major crises and uncertainty.

5.5. Net Pairwise Dynamic Connectedness

While the net total directional connectedness provides insights into which instruments are net transmitters and recipients of shocks over time in the system, it does not show the bidirectional relationships across variables. Figure 5 below shows this information on bi-directional interrelations of the transmission of shocks across the yield curve (maturity categories) for each currency basis and bi-directional relationships between cross-currency bases.

Figure 5a: Net Pairwise Directional Connectedness

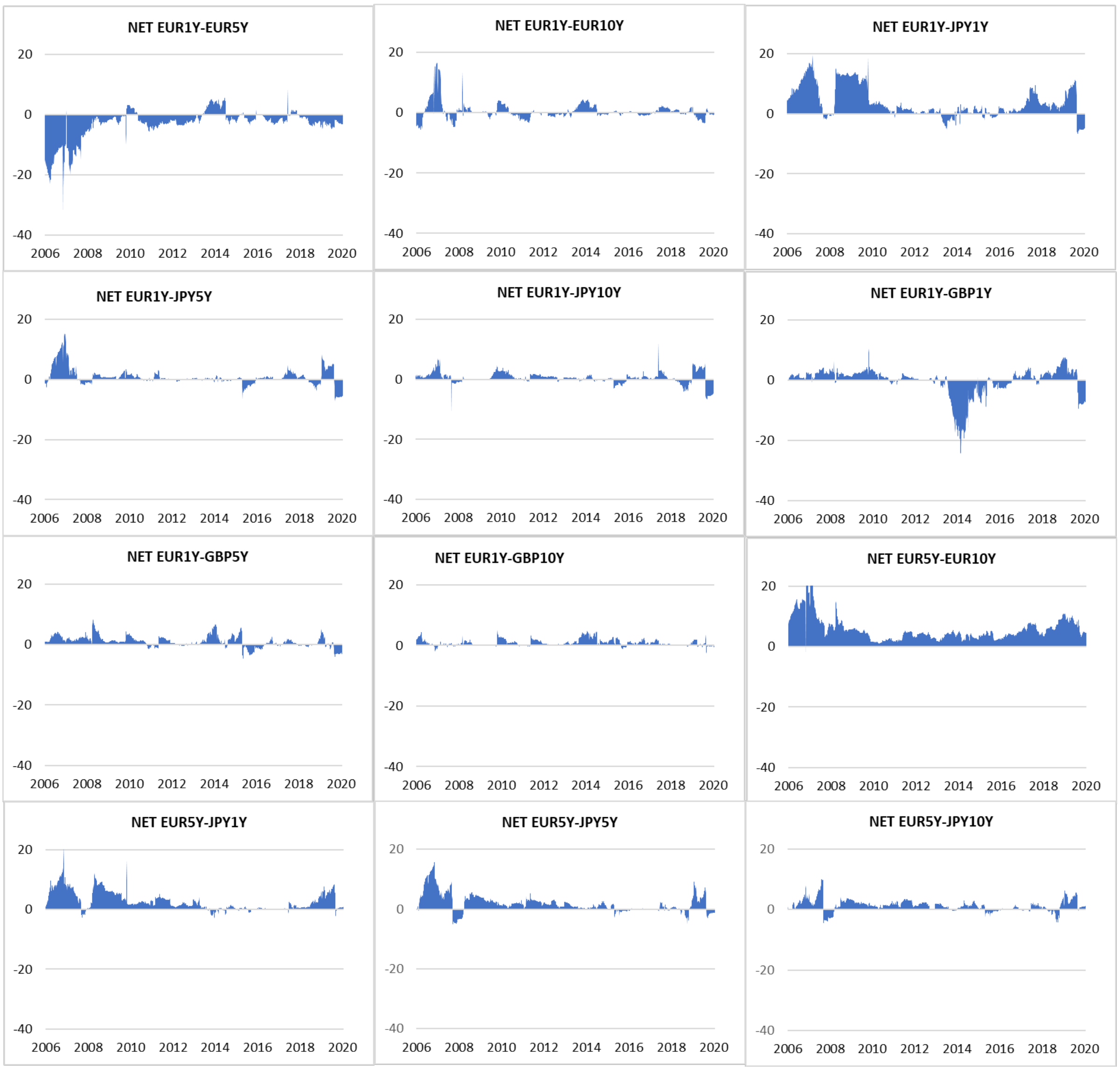


Figure 5b: Net Pairwise Directional Connectedness

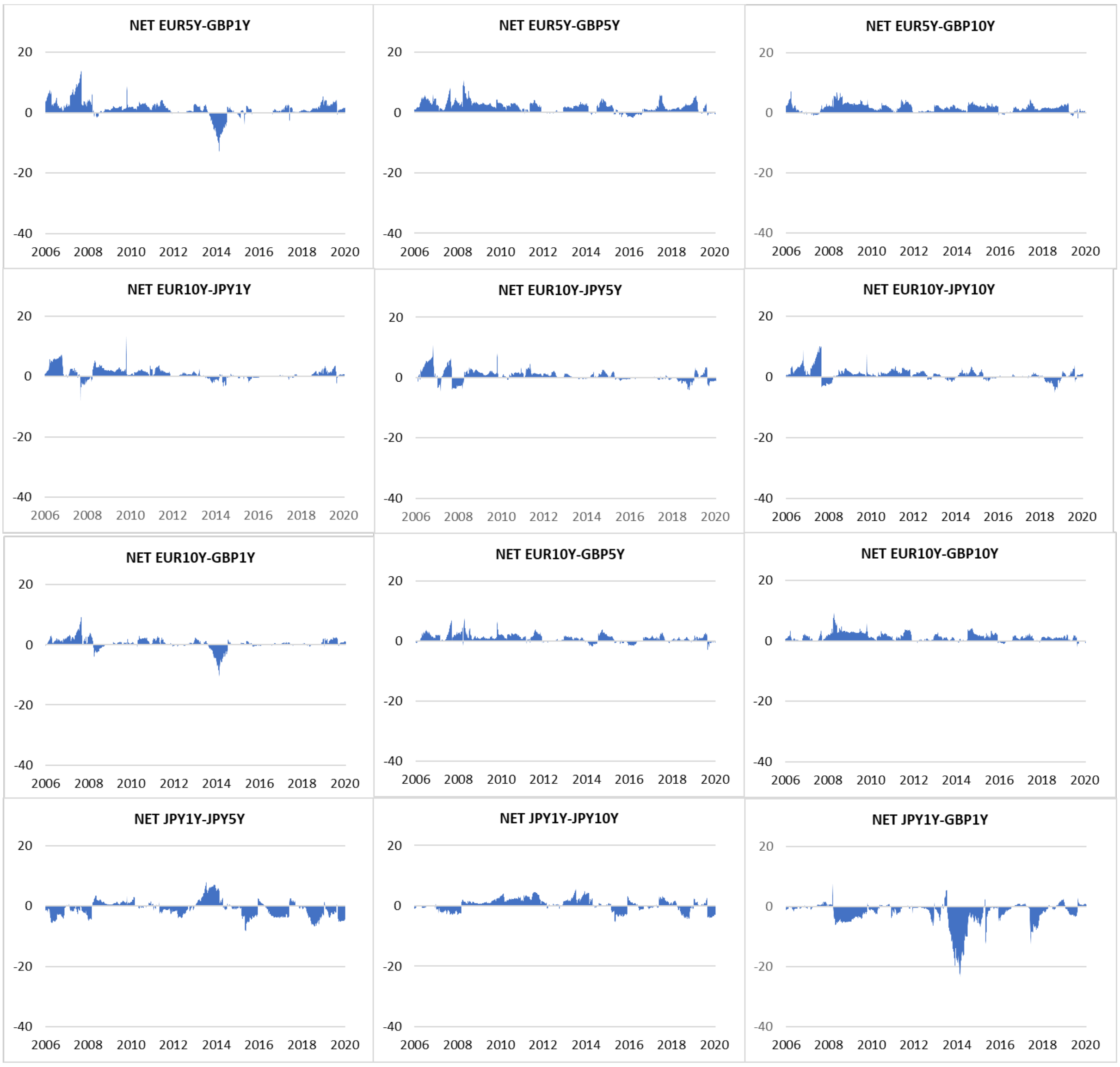
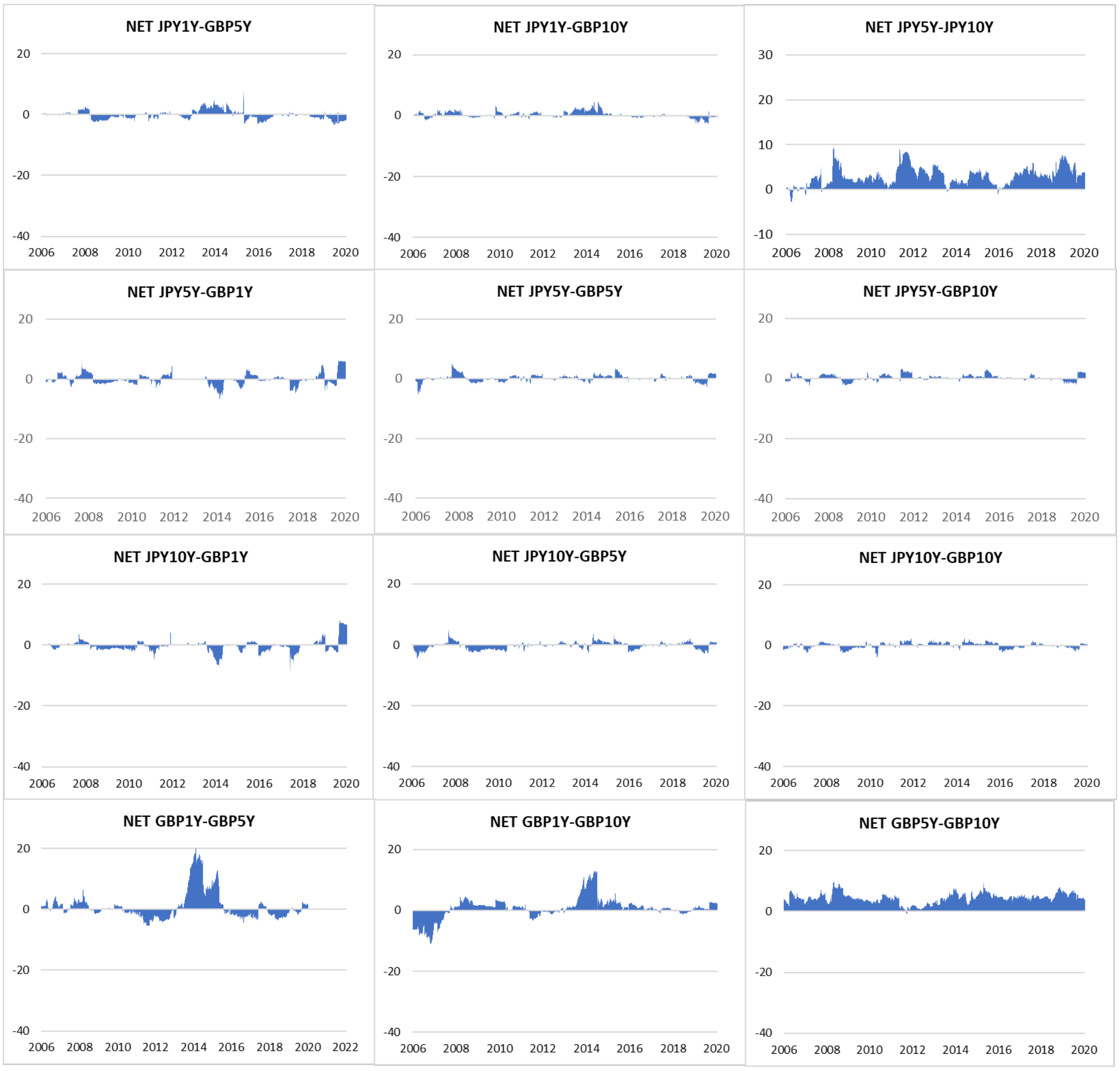


Figure 5c: Net Pairwise Directional Connectedness



Starting with the transmission of shocks across the yield curve, the medium-term segment of all cross-currency bases dominate the transmission of shocks to the long-end (see NET EUR5Y-EUR10Y, NET JPY5Y-JPY10Y and NET GBP5Y-GBP10Y). The transmission between the short-term and long-term CRSs is mixed for all currency pairs, and the same applies to the relation between short-term and medium-term.

Turning to the interrelations between CRSs across currency pairs, the USD/EUR, USD/GBP and the USD/JPY assume net transmitting or net receiver roles depending on the point in time. This is consistent with the findings by Chatziantoniou et al. (2020), which highlights that the transmission role of an instrument or variable is based on the source of the shock at a point in time. Specifically, the USD/EUR assumed a net transmission role to other currencies during the European Sovereign Debt Crisis. This is unsurprising given that it is the second most traded currency after the USD due to its fundamental role in international trade and as an official reserve currency. During the sovereign debt crisis, further dollar funding strains led to a widening of the USD/EUR basis. Consequently, these strains spilt over to other currencies.

When studying the cross-currency and cross-maturity dimensions in tandem, the following observations are notable. EUR was clearly the most prominent transmitter of shocks during the period. EUR5Y transmitted stress not only to other parts of the USD/EUR CRS yield curve. Short-term, medium-term and long-term USD/JPY and USD/GBP CRSs (Figure 5) were also affected. However, whereas USD/GBP CRSs overwhelmingly have been receivers of shocks, GBP1Y stands out as an exception during 2013-15. Notably, too, JPY1Y was a transmitter during the financial crisis of 2007-08 and the Covid-19 pandemic.

6. Conclusions

The financial crisis of 2007-08 did not mark the start of CIP deviations. They had been around before, such as during the Japanese banking crisis in the 1990s and for a range of currency pairs regularly around the end of the year. However, these were temporary episodes and quickly disappeared as normality and calm was restored to financial markets. Importantly, from the start of the financial crisis in August 2007, the CIP gradually evolved from an arbitrage equation to a benchmark and indicator of stress in the international banking system. Not surprisingly, the CIP deviation has become a tradable instrument in itself. Through CRSs, trading and hedging strategies can be put in place to bet on or protect oneself from swings in the indicator of stress – or, indeed, the expected future level of stress.

The internationalisation of the global financial system and the banking system, in particular, has resulted in increased interconnectedness. This interconnectedness increases in periods of market volatility and market stress - especially for fixed income and derivative instruments linked to money markets and foreign exchange, which remain highly bank-oriented activities (Stenfors et al., 2022). Consequently, a sudden shock in the level of stress in one banking system is likely to spread more rapidly to another.

This paper explores the transmission mechanism among CRSs quoted in the three major currency pairs, namely USD/EUR, USD/JPY and USD/GBP, from 2006 to 2022. Uniquely, we include three CRS maturities (1Y, 5Y and 10Y) to represent the short, medium and long-term market. Using a TVP-VAR model allows us not only to study how the connectedness of the "matrix" of 3x3 CRSs has evolved. It also permits us to zoom in on the transmission mechanism of each variable in the system.

Our findings show that CRS prices started to deviate (often significantly) from zero from August 2007. This led to a substantial increase in the interconnectedness of the global CRS market across currency pairs and maturities. We also document that connectedness is time-varying and elevated in periods of high volatility and market stress. The financial crisis of 2007-08, the European Sovereign Debt Crisis, the Covid-19 pandemic and a string of other events triggered larger CIP deviations and more negative CRS prices. These swings were also reflected in the transmission mechanism between CRSs for different currency pairs and maturities. Overall, we find that USD/EUR was the main transmitter of stress to the system, and this overwhelmingly took place from the medium-term yield curve segment. USD/JPY assumed a net transmitting role during 2007-08 and during the Covid-19 crisis. Despite consistently large CIP deviation, however, the currency pair has generally been a receiver of shocks. The USD/GBP cross-currency basis was more or less muted except during the 2007-08 global financial crisis and assumed a predominantly net receiving role. In fact, the USD/GBP CIP held remarkably well during 2013-15. Interestingly, this appears to have strengthened the role of the short-term USD/GBP as a transmitter. For all major currency pairs, we find that the long-term CRSs tended to be receivers of shocks. Thus, whereas the size and volatility of the deviations consistently have coincided with crises and uncertainty, the source, direction and magnitude of the transmission appears to be highly unpredictable. This poses significant challenges for policymakers attempting to mitigate the impact of stress transmitted within the international banking system.

References

Anscombe, F.J. and Glynn, W.J. (1983). Distribution of kurtosis statistic b_2 for normal samples. *Biometrica,* 70 (1), 227-234.

Antonakakis, N., Chatziantoniou. I. and Gabauer, D. (2020). Refined Measures of Dynamic Connectedness on Time-Varying Parameter Vector Autoregressions. *Journal of Risk and Financial Management*,13(4), 84.

Avdjiev, S., Eren, E. and McGuire, P. (2020). Dollar funding costs during the Covid-19 crisis through the lens of the FX swap market, Bank for International Settlements, Bulletin No.1. Available at: https://www.bis.org/publ/bisbull01.pdf [Accessed 20 September 2022].

Baba, N. and Packer, F. (2009). Interpreting deviations from covered interest parity during the financial market turmoil of 2007–08. *Journal of Banking & Finance*, 33 (11), 1953-1962.

Baruník, J. , Kočenda, E. and Vácha, L. (2016). Asymmetric connectedness on the U.S. stock market: Bad and good volatility spillovers. *Journal of Financial Markets,* 27, 55-78.

Borio, C. McCauley, R., McGuire, P. and Sushko, V. (2016). Covered interest parity lost: understanding the cross currency basis. BIS Quarterly Review. September 2016. Available at: https://www.bis.org/publ/qtrpdf/r_qt1609e.pdf [Accessed 12 September 2022].

Borio, C.E.V., Iqbal, M., McCauley, R. N. and McCauley, McGuire, P.M. and Sushko, V. (2018). The Failure of Covered Interest Parity: FX Hedging Demand and Costly Balance Sheets. October 4. BIS Working Papers, No. 590, Available at: https://ssrn.com/abstract=2910319 [Accessed 12 October 2022].

Brophy, T., Herrala, N., Jurado, R., Katsalirou, I., Le Quéau, L. and O'Donnell, S. (2019). Role of cross currency swap markets in funding and investment decisions. ECB Occasional Paper, (228). Available at: https://www.ecb.europa.eu/pub/pdf/scpops/ecb.op228~bb3e50120a.en.pdf [Accessed 19 September 2022].

Chatziantoniou, I., Gabuer, D. and Stenfors, A. (2020). From CIP-deviations to a market for risk premia: A dynamic investigation of cross-currency basis swaps. *Journal of International Financial Markets, Institutions and Money,* 69, 101245.

Chatziantoniou, I., Gabuer, D. and Stenfors, A. (2021). Interest rate swaps and the transmission of monetary policy: A quantile connectedness approach. *Economic Letters,* 109891.

Coffey, N., Hrung, W.B. and Sarkar, A. (2009). Capital Constraints, Counterparty Risk, and Deviations From Covered Interest Rate Parity. Federal Reserve Bank of New York Staff Reports, no. 393, September 2009. Available at: https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr393.pdf [Accessed 12 October 2022].

Correa, R., Sapriza, H. and Zlate, A. (2012). Liquidity Shocks, Dollar Funding Costs, and the Bank Lending Channel During the European Sovereign Crisis. Board of Governors of the Federal Reserve System. International Finance Discussion Papers, Number 1059, November 2012. Available at: https://www.federalreserve.gov/pubs/ifdp/2012/1059/ifdp1059.pdf [Accessed 12 October 2022].

D'Agostino, R.B. (1970). Transformation to normality of the null distribution of g1. *Biometrika,* 57 (3): 679-681.

Diebold, F.X. and Yilmaz, K. (2009). Measuring financial asset return and volatility spillovers, with application to global equity. *The Economic Journal,* 119, 158-171.

Diebold, F.X. and Yilmaz, K. (2012). Better to give than to receive predictive directional measurement of volatility spillovers. *International Journal of Forecasting,* 28, 57-66.

Diebold, F.X. and Yilmaz, K. (2014). On the network topology of variance decompositions: Measuring the connectedness of financial firms. *Journal of Econometrics,* 182, 119- 134.

Du, W., Tepper, A. and Verdelhan, A. (2018). Deviations from covered interest rate parity. *The Journal of Finance*, 73 (3), 915-957.

Einzig, P. (1937). *Theory of Forward Exchange*. Macmillan & Company: London.

Elliot, G., Rothenberg, T.J. and Stock, James, J.H. (1996). Efficient Tests for an Autoregressive Unit Root. *Econometrica,* 64 (4), 813-836.

Fisher, T.J. and Gallagher, C.M. (2012). New Weighted Portmanteau Statistics for Time Series Goodness of Fit Testing, *Journal of the American Statistical Association,* 107 (498), 777-787.

Gabauer, D., Gupta, R., Marfatia, H. and Miller, S. (2020). Estimating US Housing Price Network Connectedness: Evidence from Dynamic Elastic Net, Lasso, and Ridge Vector Autoregressive Models (No. 202065). The University of Pretoria, Department of Economics. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3660950 [Accessed 21 September 2022].

Genberg, H., Hui, C.-H., Wong, A. and Chung, T.-K. (2011). The Link between FX Swaps and Currency Strength during the Credit Crisis of 2007–2008. In Cheung, Y.-W., Kakkar, V. and Ma, G. (Editors.) *The Evolving Role of Asia in Global Finance*, Emerald Group Publishing Limited, Bingley, pp. 83-94.

Giannetti, M. and Laeven, L. (2012). Flight home, flight abroad, and international credit cycles. *American Economic Review: Papers & Proceedings*, 102 (3), 219–224.

Grifolli, T.M. and Ronaldo, A. (2012). Limits to Arbitrage During the Crisis: Funding Liquidity Constraints and Covered Interest Parity. Technical report. Swiss Institute of Banking and Finance (S/BF – HSG), Working Papers on Finance, no. 2012/12. University Of St. Gallen School of Finance. Available at: http://ux-tauri.unisg.ch/RePEc/usg/sfwpfi/WPF-1212.pdf [Accessed 12 October 2022].

Iida, T., Kimura, T. and Sudo, N. (2016). Regulatory reforms and the dollar funding of global banks: Evidence from the impact of monetary policy divergence. Bank of Japan Working Paper Series, No.16 E 14. Available at: https://www.boj.or.jp/en/research/wps_rev/wps_2016/data/wp16e14.pdf [Accessed 12 October 2022].

Ivashina, V., Scharfstein, D.S. and Stein, J.C. (2015). Dollar funding and the lending behavior of global banks. *The Quarterly Journal of Economics*. 130 (3), 1241–1281.

Jarque, C.M. and Bera, A.K. (1980). Efficient tests for normality, homoscedasticity and serial independence of regression residuals. *Economics Letters,* 6 (3), 255-259.

Kang, S. H., McIver, R. and Yoon, S. (2017). Dynamic spillover effects among crude oil, precious metal, and agricultural commodity futures markets. *Energy Economics*, 62, 19-32.

Keynes, J.M., (1923). *A Tract on Monetary Reform*. Macmillan: London.

Koop, G., Pesaran, M.H., Potter, S.M. (1996). Impulse response analysis in nonlinear multivariate models. *Journal of Econometrics*, 74, 119–147.

McGuire, P. and von Peter, G. (2012). The dollar shortage in global banking and the international policy response. *International Finance*, 15 (2), 155–178.

Peek, J. and Rosengren, E. S. (2000). Collateral damage: Effects of the Japanese bank crisis on real activity in the United States. *American Economic Review*, 90 (1), 30-45.

Pesaran, H.H. and Shin, Y. (1998). Generalized impulse response analysis in linear multivariate models. *Economics Letters,* 58, 17-29.

Sims, C. (1980). Macroeconomics and reality. *Econometrica*, 48 (1), 1–48.

Spiegel, M. (2001). The Return of the "Japan Premium": Trouble Ahead for Japanese Banks? FRBSF Economic Letter, March 9, Federal Reserve Bank of San Francisco. Available at: https://www.frbsf.org/economic-research/publications/economic-letter/2001/march/the-return-of-the-japan-premium-trouble-ahead-for-japanese-banks/ [Accessed 12 October 2022].

Stenfors, A. (2014a). LIBOR as a Keynesian beauty contest: a process of endogenous deception. Rev. Polit. Econ. 26 (3), 392–407.

Stenfors, A. (2014b). LIBOR deception and central bank forward (mis-)guidance: Evidence from Norway during 2007–2011. *Journal of International Financial Markets, Institutions and Money*, 32, 452–472.

Stenfors, A. (2019). The covered interest parity puzzle and the evolution of the Japan Premium. *Journal of Economic Issues*, 53 (2), 417- 424.

Stenfors, A., Chatziantoniou, I. and Gabuer, D. (2022). Independent policy, dependent outcomes: A game of cross-country dominoes across European yield curves, *Journal of International Financial Markets, Institutions and Money,* 81, 101658.

Thomas J. F. and Colin M. G. (2012). New Weighted Portmanteau Statistics for Time Series Goodness of Fit Testing. *Journal of the American Statistical Association*, 107 (498), 777-787.