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# From CIP-Deviations to a Market for Risk Premia:

## A Dynamic Investigation of Cross-Currency Basis Swaps

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**Abstract**

The persistent deviations from the covered interest rate parity (CIP) since 2007 indicate that specific frictions continue to exist, which prevent them from being arbitraged away. In this study, we study the cross-currency basis swap market and put forward the argument that the risk premium expressed via the CIP-deviation constitutes a unique market that determines its own equilibrium price after receiving feedback from various sources, including contagion within the market itself. We investigate contagion using a TVP-VAR framework of analysis that measures the extent of connectedness across the bases on all G10 currencies against the US dollar between 2007 and 2018. Our main findings indicate that connectedness is event-dependent. Furthermore, we provide evidence that net-transmitting bases are typically associated with safe haven currencies (e.g. CHF) and banking sectors with significant overseas operations (e.g. EUR and JPY). On a pairwise level, results confirm that during tranquil times in international financial markets, connectedness subdues and even reaches negligible levels - particularly for stable banking systems (e.g. CAD) or without significant US dollar funding gaps (e.g. AUD).

**Keywords:** CIP-Deviations; Cross-Currency Basis Swaps; Dynamic Connectedness; Spillover Analysis; TVP-VAR.

**JEL codes:** C32; C5; F3; G15.

## 1 Introduction

The covered interest rate parity (CIP) is one of the most important equations in international economics and which, according to Borio et al. (2016) 'verges on a physical law in international finance'. Analysed from the perspective of arbitrage, a violation of the CIP is typically associated with stress in the international financial system. This was particularly evident during the financial crisis of 2007-08, but also during the Japanese banking crisis in the 1990s. However, the persistent failure of the CIP since the financial crisis has puzzled academics and policymakers alike. Explanations are wide-ranging and include, for instance, the importance of monetary policy divergence and the search for yield in a low-interest environment (Iida et al., 2016); the capital needed in exploiting arbitrage opportunities in international money markets (Ivashina et al., 2015); and the relevance of balance sheet constraints and point to a combination of foreign exchange (FX) hedging demand and tighter limits to arbitrage (Sushko et al., 2016). Thus, the research agenda has mainly focussed on frictions causing CIP-deviations that are not arbitraged away by financial market participants.

Our paper takes a different approach. In contrast with previous studies, we do not attempt to explain or decompose the risk premia expressed through the CIP-deviations. What is more, we consider deviations from the CIP to be persistent (i.e., as opposed to zero-reverting) and under this prism, such deviations rather constitute a separate market that determines its own equilibrium price within a dynamic global environment which in turn, is subject to various sources of risk. The market in question is that of cross-currency basis swaps (CRS). Our cross-country study covers the period from 2007 to 2018 and includes all G10 currencies against the US dollar (USD), i.e. the Australian dollar (AUD), the Canadian dollar (CAD), the Swiss franc (CHF), the Danish krone (DKK), the euro (EUR), the British pound (GBP), the Japanese yen (JPY), the Norwegian krone (NOK), the New Zealand dollar (NZD) and the Swedish krona (SEK). The currency pairs selected account for close to 90% of the turnover in the global FX and CRS market (BIS, 2016). Detailed examinations of the CRS market remain rare in the academic literature, despite contracts amounting to $25.9 trillion being outstanding (BIS, 2016). More urgently, our investigation addresses disturbances within the first stage of the monetary transmission mechanism and therefore adds to the literature seeking to explain, decompose and quantify potential drivers of money market risk premia (see, for instance, Du et al., 2018).

Our empirical approach extends the seminal connectedness method introduced by Diebold and Yılmaz (2012, 2014) as we obtain results from a time-varying parameters Vector Autoregressive (TVP-VAR) model in the spirit of Antonakakis and Gabauer (2017) and Korobilis and Yilmaz (2018). The underlying method, practically corrects the measurement deficiencies of the standard rolling-windows approach by (i) eliminating the distorting effects of irregular observations, (ii) not having to make an arbitrary choice in relation to the forecast horizon and the window length of the sample, as well as (iii), not excluding observations through progressing across different windows. By considering the relevant connectedness measures of different cross-currency bases, we are able to identify a measure of risk for the particular market that goes beyond the fundamental analysis of frictions causing arbitrage opportunities to prevail (such as credit and liquidity risk or regulatory balance sheet requirements). In particular, we identify a measure of risk that stems directly from contagion dynamics across premiums of different cross-currency contracts; that is, from contagion dynamics within the market itself.

Our findings suggest that, total connectedness - within the network of cross-currency bases under investigation - varies with time and that these fluctuations might, in turn, be attributed to specific events in connection with developments in international financial markets. Furthermore, the USD/EUR-basis appears to be an enduring net-transmitter of US dollar funding liquidity shocks to other bases, which in turn is telling of the rather turbulent banking system of the Eurozone. Cross-currency bases that assume a net-transmitting role for most of the period of study are typically bases linked to banking systems that have undergone specific episodes of US dollar funding gaps. In a testament to that, USD/JPY cross-currency swaps also assume a net-transmitting role following the expansion of Japanese banks abroad.

Besides, the USD/GBP basis was a net-transmitter during the Northern Rock period. On a different note, we find that for CHF and DKK, being pegged to the EUR determines to a great extent whether the respective cross-currency basis assumes a net-transmitting or a net-receiving role. Finally, we provide evidence of decoupling which is typically realised by lower levels of connectedness and also facilitates our understanding of the persistent character of specific cross-currency bases (e.g., USD/AUD and USD/CAD) as net-receivers of shocks.

In retrospect, the dynamic nature of connectedness across cross-currency bases justifies the main argument of our study that CIP-deviations will not necessarily be arbitraged away and that in this respect, they deserved to be regarded as a unique market that determines its equilibrium price through the influence of various sources of risk originating in international financial markets. Within the framework of our study, a specific cross-currency basis may very well be determined by the extent of its connectedness to other cross-currency bases. The position of each basis as a net-transmitter or net-receiver of US dollar shortages depends significantly on the specific period under investigation, as well as, on the underlying dynamics of the economy and the banking sector. The remainder of this paper is organised as follows. In Section 2 we present the relevant literature review and hypotheses that emerge. In Section 3, we describe the data and set out the empirical methods employed in the study. In Section 4, we illustrate the findings of the study and discuss the relevant arguments. Finally, Section 5 summarises the key elements, provides a framework for policy implications and concludes the study.

## 2 Background & Related Literature

The CIP is a central equation in economics, and the related literature can be tracked back a whole century (see, for instance, Keynes, 1923; Einzig, 1937). Borio et al. (2016) go so far as to state that the CIP "verges on a physical law in international finance." The equation is simple and states that the interest rate differential between two currencies should be perfectly reflected in the FX prices. Hence:

$$e^{ti_t} = e^{ti_t^*} \frac{S_t}{F_t} \tag{1}$$

where $i_t$ and $i_t^*$ are the continuously compounded base and counter currency interest rates, respectively, for maturity $t$. $S_t$ and $F_t$ are the FX spot and FX forward rate between the base and the counter currency.

In log-terms, the continuously compounded forward premium, $\rho_t$, is equal to the interest rate differential of the two currencies:

$$\rho_t = \tfrac{1}{t}(F_t - S_t) = i_t^* - i_t \tag{2}$$

The CIP is typically analysed from the perspective of covered interest arbitrage. For instance, it should not be possible to generate risk-free profits by borrowing in the base currency at the prevailing interest rate, exchanging the amount at the FX spot rate, lending in the counter currency and, finally, exchange it back at the FX forward rate. Thus, ignoring bid-ask spreads, arbitrage activities, it is assumed, will drive the CIP-deviation to zero.

As we shall see, however, this is not the case in practice, which is why an additional term is added to the equation: the cross-currency basis. The continuously compounded cross-currency basis, $x_t$, can be seen as the CIP-deviation between two currency pairs for maturity $t$:

$$e^{ti_t} = e^{ti_t^* + tx_t} \frac{S_t}{F_t} \tag{3}$$

Thus, the cross-currency basis expressed in logs is:

$$x_t = \frac{F_t}{S_t}(1 + i_t) - (1 + i_t^*) \tag{4}$$

FX forwards are rarely traded in the interbank market. Instead, FX swaps are used in conjunction with the FX spot rate to construct FX forwards synthetically – an FX swap is a combination of an FX spot transaction plus an FX forward transaction done simultaneously but in the opposite direction. Hence, the FX swap price is a reflection of the interest rate differential between two currencies. Using derivatives terminology, the cashflows in an FX swaps are identical to that of a 'zero-coupon fixed-fixed cross-currency swap'.

According to BIS (2016), the average daily turnover of the FX swap market amounted to over \$2.3 trillion. However, close to 99% are for maturities of up to 1 year. To express the cross-currency basis for longer maturities, therefore, another instrument is used: the cross-currency basis swap (CRS). A CRS is a floating-floating interest rate swap, where periodic cashflows are exchanged between two counterparties, as well as a notional amount in two currencies at inception and maturity of the swap. Interest rate benchmarks, such as London Interbank Offered Rate (LIBOR), are used to determine the floating rate coupons (which typically are three months). The 'price' of the CRS is expressed in the cross-currency basis, $x_t^{XCCY}$, where the counterparties agree to exchange floating cashflows in one currency against floating cashflows in another currency. For instance, a 1-year USD/JPY CRS trading at -10 indicates that market participants are prepared to borrow (lend) US dollars at 3-month USD LIBOR against lending (borrowing) Japanese yen at 3-month JPY LIBOR minus 10 basis points for one year.

Technically, a CRS can be decomposed into a zero-coupon fixed-fixed cross-currency swap and two plain-vanilla fixed-for-floating interest rate swaps (IRS) in two currencies and opposite directions. We can write:

$$e^{ti_t^{IRS}} = e^{ti_t^{IRS*}+tx_t^{XCCY}} \frac{S_t}{F_t} \tag{5}$$

The long-term forward premium becomes:

$$\rho_t = \frac{1}{t}(F_t - S_t) = i_t^{IRS} - x_t^{XCCY} - i_t^{IRS*} \tag{6}$$

To sum up, the cross-currency basis, $x_t^{XCCY}$, is the CIP-deviation expressed from the perspective of the counter currency.

## 2.1 The Evolution Towards the 'CIP Puzzle'

Before the financial crisis of 2007-08, deviations from the CIP were generally minimal and short-lived (Akram et al., 2008). Put differently; the cross-currency basis was close to zero. A notable exception to this rule, however, was during the Japanese banking crisis in the 1990s, when the USD/JPY cross-currency basis turned sharply negative. Figure 1 illustrates, for instance, that Japanese banks were required to pay a premium of more than 35 basis points in late 1998 to borrow US dollars via the 1-year USD/JPY cross-currency basis swap market.

[Insert Figure 1 around here]

Suddenly being perceived as less creditworthy than their peers, Japanese banks struggled to raise foreign currency (and mainly US dollar) funding during the crisis. The Bank of Japan could supply ample liquidity in Japanese yen, which served to dampen the domestic money market risk premia. However, having made significant investments abroad, the unsecured non-yen money market dried up for Japanese banks. As a result, they were required to use FX and cross-currency basis swaps to generate the foreign currency needed to cover their funding requirements. This resulted in substantial CIP-deviations, which showed that the implied US dollar interest rate via the Japanese yen and the FX swap market was considerably higher than the direct US dollar interest rate in the interbank money market (which Japanese banks were unable to access).

After almost a decade of stability following the Japanese banking crisis, the cross-currency basis started to deviate again in August 2007. The CIP-deviations during the financial crisis of 2007-08 were, similarly to other money risk premia such as the LIBOR-OIS spread, triggered by a combination of increased counterparty credit risk and funding liquidity risk - particularly following the collapse of Lehman Brothers (Coffey et al., 2009; Genberg et al., 2011; Griffoli and Ranaldo, 2011). In contrast to the Japanese banking crisis, however, the financial crisis of 2007-08 was not country-specific. Instead, all G10 currency pairs (as well as a range of others) involving the US dollar experienced sharp and volatile CIP-deviations.

[Insert Figure 2 around here]

As can be seen from Figure 2, the cross-currency basis has been negative for most currency pairs against the US dollar. Like during the Japanese banking crisis, domestic liquidity injections were not sufficient to eliminate the cross-currency bases. This time, however, the Federal Reserve stepped in to establish FX swap lines with a series of central banks. Through this coordinated international central bank action, liquidity could be channelled to non-US banks, which faced significant US dollar funding shortages (Baba and Packer, 2009; McGuire and von Peter, 2012). The establishment of the FX swap network was successful in the sense that it influenced the market sentiment, which quickly helped to reduce the cross-currency basis for a range of currency pairs. However, in contrast to the aftermath of the Japanese banking crisis, 'normality' has not returned to zero. Instead, volatility has remained high, and deviations from the CIP have been considerable - particularly during the Eurozone crisis and the US money market mutual fund (MMMF) reform in October 2016 (Aldasoro et al., 2017, 2018). Thus, CIP-deviations appear to have become persistent despite extraordinary measures by policymakers around the world and, perhaps more importantly, a return to relative stability in the international financial system. As a result, new explanations for the 'CIP puzzle' have emerged, which focus less on (perceived) credit and funding liquidity risk. Instead, greater emphasis has been put on the role of the US dollar, cross-border lending and balance sheet constraints preventing the non-arbitrage condition to be fully restored.

The US dollar plays a crucial role in the CIP not only by being the dominant currency in FX and CRS transactions but also by acting as a significant currency in borrowing and lending activity by non-US banks (Ivashina et al., 2015). Indeed, using data from 2007 to 2016, Avdjiev et al. (2019) document a triangular relationship between CIP-deviations, the strength of the US dollar and dollar-denominated cross-border lending[1]. A stronger US dollar has a negative impact on the balance sheet of banks, which, in turn, puts pressure on the cross-currency basis[2]. Moreover, they find that the cross-currency basis of 'safe haven' currencies (such as JPY and CHF) are most affected, and high-yielding currencies on the opposite side of typical carry trades (such as AUD and NZD) least affected, by the strength of the US dollar.

The critical role of balance sheet constraints is also reported by Sushko et al. (2016). As the authors note, the US dollar hedging demand by financial institutions shows important cross-country variations.

[1] In similar vein, Genberg et al. (2011) find that risk premia are negatively correlated with the strength of the domestic currency.

[2] As Bruno and Shin (2015) demonstrate, a stronger US dollar acts to decrease US dollar credit supply.

On the aggregate, most G10 banking systems have significant US dollar 'funding gaps', i.e. more US dollar assets than liabilities. This, following Borio et al. (2016), leads to a process whereby banks become prevented from arbitraging away the cross-currency basis, which emerges from the typically one-sided FX hedging demand by institutional investors. For a selected few banking systems, however, the situation is the reverse (notably Australia) - which acts to offset the US dollar hedging demand by institutional investors. This could, in part, serve to explain the peculiar (consistently positive) cross-currency basis for USD/AUD and USD/NZD since the financial crisis of 2007-08.

As the investigations above show, the cross-currency basis is not only of interest from an arbitrage perspective. It is also an essential indicator of the stress in the international financial system (Stenfors, 2019). Importantly, US dollar funding shortages as expressed in the cross-currency basis do not only affect non-US banks and the stability of the banking systems of the home country. The process might also have spillover effects on the US real economy - especially corporations borrowing from foreign banks (Acharya et al., 2017). This was already observed during the Japanese banking crisis when US subsidiaries of Japanese banks sharply reduced their lending (Peek and Rosengren, 2000). Along the same lines, Correa et al. (2012) show that the liquidity shocks suffered by US branches of Eurozone banks had real economy effects in the US during the Eurozone sovereign debt crisis. These findings echo those by Giannetti and Laeven (2012b), who find that, following liquidity shocks, bank lending to foreigners is reduced more than that to domestic borrowers - thereby triggering a 'flight home' effect within the international money markets. The internationalisation of the banking system appears to have resulted in an amplification of such shocks Giannetti and Laeven (2012a). Put differently, strains in the FX swap and CRS markets may force non-US banks to reduce their US dollar lending, which, in turn, may contribute to global financial instability (Iida et al., 2016). Thus, the cross-currency basis can play a significant role in policymaking and vice versa. This was already noted during the Japanese banking crisis (Peek and Rosengren, 2001). A wide range of policy measure to address the crisis, including the commitment of Bank and Japan and the Ministry of Finance to act as Lender of Last Resort, influenced the cross-currency basis by strengthening the financial position of the Japanese banks (Spiegel, 2001). However, they also acted to change the perceptions by financial market participants.

In sum, the cross-currency basis appears to be influenced by credit and funding liquidity risk in the banking sector. However, as the basis is highly dependent on diverse currency funding gaps in an increasingly international financial system, other drivers also matter - ranging from FX swap networks among central banks to balance sheet requirements imposed by regulators. The research agenda, then, has focussed on various frictions preventing market participants from arbitraging away CIP deviations that have already emerged. Thus, treating the CIP-deviation as 'puzzle' suggests that the basis is seen as a price, which should have an underlying tendency to drift towards zero. Such a perspective probably explains why relatively few have attempted to explain the direction or the size of the basis, or treated the CIP-deviation as an equilibrium outcome at the outset (with notable exceptions such as Ivashina et al., 2015).

In contrast to previous studies, however, we do attempt to explain, decompose or quantify the cross-currency basis - which has arisen as a result of factors outlined above. Rather than treating the CIP-deviation as a puzzle at the outset, our approach does not assume that it will return to zero. Instead, our focus lies on the connectedness of CRS markets themselves, and the spillovers between them. Importantly, the cross-currency basis, as an indicator of (the fear of) stress in the international financial system, can be treated as a price. The cross-currency basis is traded via the CRS market or constructed synthetically via the FX swap market. As Stenfors (2014a,b, 2018) shows, benchmarks, prices and spreads linked to interest rate markets have a tendency display extreme levels of 'stickiness' - due to being anchored to stable official central bank rates. In this respect, the natural 'anchor' of the cross-currency basis has historically been zero; in other words, a market in which arbitrage activities eliminate all CIP-deviations. However, as has been widely demonstrated, cross-currency bases can no longer be treated as short-term and temporary. By becoming the norm since August 2007, market participants have gradually grown accustomed to no longer to expect CIP-deviations to return to zero. This is important, as it increases the relevance and attention to the anticipated cross-currency bases (i.e. CIP-deviations) in the future, rather than the arbitrage activities driving them towards zero (see Keynes, 1923). Indeed, the role of future expectations is particularly relevant for the CRS market by being a banking activity and inherently opaque. The lack of transparency makes it challenging for market participants to accurately assess the creditworthiness and liquidity position of other banks continuously. This increases the need to 'glance' at other related markets to get an indication of the likely future direction of prices and risk premia. There are, of course, numerous other risk premia and benchmarks that, when deviating from zero, indicate stress or fear in the financial system. Cash or derivatives markets enable market participants to buy or sell a range of indicators of 'fear', many of these are both opaque and traded OTC (Stenfors and Lindo, 2018; Stenfors, 2019). Perceived liquidity and credit risk in the banking system can also be traded via LIBOR-OIS spreads, 3s6s basis swaps, asset swaps or credit default swap (CDS) spreads. What sets the CRS market apart is that it is international by definition.

# 3 Data & Methodology

## 3.1 Cross-Currency Basis Data

Our cross-country study covers the period from 2007 to 2018 and includes all G10 currencies against USD, i.e. AUD, CAD, CHF, DKK, EUR, GBP, JPY, NOK, NZD and SEK.

The cross-currency basis can be expressed in several ways, e.g. (i) derived from FX contracts and interest rate benchmarks such as LIBOR, (ii) derived from FX contracts and OIS, and (iii) directly observed from the CRS market. There is no liquid OIS market for several of the smaller currencies. In our study, therefore, we use mid-market daily end-of-day 1-year CRS prices from Bloomberg. By opting for the 1-year maturity, we capture the only segment of the market, which has a liquid FX and CRS market.

Cross-currency basis swaps are floating-floating swaps for a specific maturity. Following the market convention, the floating rates benchmark used is the 3-month USD LIBOR and the 3-month benchmark in the other currency (plus/minus the premium expressed in basis points, i.e. the 'cross-currency basis'). The 3-month benchmarks for the other currencies are: AUD: Bank Bill Swap Rate (BBSW); CAD: Canadian Dollar Offered Rate (CDOR); CHF: LIBOR; DKK: Copenhagen Interbank Offered Rate (CIBOR); EUR: Euro Interbank Offered Rate (EURIBOR); GBP: LIBOR; JPY: LIBOR; NOK: Norwegian Interbank Offered Rate (NIBOR); NZD: Bank Bill Market Rate (BKBM); and SEK: Stockholm Interbank Offered Rate (STIBOR). Thus, 1-years CRSs enable us not only to explore the transmission mechanism of the very short-term cross currency basis as expressed in the FX market (for, say, three months), but also to incorporate expectations of future deviations through the remaining three coupons of the swap.

As the CRS series are non-stationary according to the ERS (Stock et al., 1996) unit-root test we decide to take the first log-differences that can be interpreted as the daily percentage changes. The resulting series are illustrated in Figure 3.

[Insert Figure 3 around here]

Missing values of the CRS series have been imputed using the Kalman filter (see, Durbin and Koopman, 2012). The transformed series build the fundament of the summary statistics which are shown in Table 1. The findings indicate that the series are significantly non-normally distributed (D'Agostino, 1970; Anscombe and Glynn, 1983; Jarque and Bera, 1980) and stationary on at 1% significance level. Notably, we find pronounced autocorrelation in both, the series and squared series (Fisher and Gallagher, 2012) implying that the mean and the variance of each series varies over time. Thus, employing a TVP-VAR model with a time-varying variance-covariance structure seems to be an appropriate econometric framework capturing all those factors.

[Insert Table 1 around here]

### 3.2 TVP-VAR-Based Dynamic Connectedness Approach

A widely used framework to trace and evaluate spillovers in a predetermined network is the connectedness approach proposed by Diebold and Yılmaz (2009, 2012, 2014). The constantly increasing attention this framework experiences is mainly caused by the fact that it provides researchers and practitioners with a static and dynamic method of time series network analysis. The static approach is employing a vector autoregressive model (VAR, see Sims, 1980) on the full dataset whereas the dynamics are estimated via a rolling-window VAR approach. The setting of this framework is discussed intensively in Antonakakis and Gabauer (2017); Korobilis and Yilmaz (2018) and Antonakakis et al. (2019) who are proposing a dynamic connectedness approach based on time-varying parameter vector autoregressions with the result that dynamics aren't influenced by the size of the rolling window. Additional advantages of the TVP-VAR based connectedness approach are (i) the outlier insensitivity caused by the underlying Kalman filter, (ii) that there is no need to arbitrarily choose the rolling-window size, (iii) that there is no loss of observations and (iv) that it can be employed also for low frequency datasets. This study applies the same methodology as in Antonakakis et al. (2018) and (Gabauer and Gupta, 2018)[3]. In particular, we are estimating a TVP-VAR(1) as suggested by the Bayesian information criterion (BIC) which can be outlined as:

$$\boldsymbol{z}_t = \boldsymbol{B}_t \boldsymbol{z}_{t-1} + \boldsymbol{u}_t \qquad \boldsymbol{u}_t \sim N(\boldsymbol{0}, \boldsymbol{S}_t) \tag{7}$$

$$vec(\boldsymbol{B}_t) = vec(\boldsymbol{B}_{t-1}) + \boldsymbol{v}_t \qquad \boldsymbol{v}_t \sim N(\boldsymbol{0}, \boldsymbol{R}_t) \tag{8}$$

where $\boldsymbol{z}_t$, $\boldsymbol{z}_{t-1}$ and $\boldsymbol{u}_t$ are $k \times 1$ dimensional vector and $\boldsymbol{B}_t$ and $\boldsymbol{S}_t$ are $k \times k$ dimensional matrices. $vec(\boldsymbol{B}_t)$ and $\boldsymbol{v}_t$ are $k^2 \times 1$ dimensional vectors whereas $\boldsymbol{R}_t$ is a $k^2 \times k^2$ dimensional matrix.

Subsequently, we are calculating the $H$-step ahead (scaled) generalized forecast error variance decomposition (GFEVD) introduced by Koop et al. (1996) and Pesaran and Shin (1998). Notably, the GFEVD is completely invariant of the variable ordering opposed to the orthorgonalized forecast error variance decomposition (See, Diebold and Yılmaz, 2009). Please keep in mind that the structural representations of shocks – as it is often used in applied macroeconomics – should only be used if it underlies an economic theory which is – to the best of our knowledge – not available when it comes to the daily cross-currency basis swaps market[4]. For this reason, we stick to the GFEVD spillover framework. Since this concept is build upon the Wold representation theorem which allows to transform the estimated TVP-VAR model into a TVP-VMA process by making use of the following equality: $\boldsymbol{z}_t = \sum_{i=1}^{p} \boldsymbol{B}_{it} \boldsymbol{z}_{t-i} + \boldsymbol{u}_t = \sum_{j=0}^{\infty} \boldsymbol{A}_{jt} \boldsymbol{u}_{t-j}$.

The (scaled) GFEVD normalizes the (unscaled) GFEVD, $\phi^g_{ij,t}(H)$, in order that each row sums up to unity. Hence, $\tilde{\phi}^g_{ij,t}(H)$ represents the influence variable $j$ has on variable $i$ in terms of its forecast error variance share which is defined as the *pairwise directional connectedness from $j$ to $i$*. This indicator is computed by,

$$\phi^g_{ij,t}(H) = \frac{S^{-1}_{ii,t} \sum_{t=1}^{H-1} (\boldsymbol{\iota}'_i \boldsymbol{A}_t \boldsymbol{S}_t \boldsymbol{\iota}_j)^2}{\sum_{j=1}^{k} \sum_{t=1}^{H-1} (\boldsymbol{\iota}_i \boldsymbol{A}_t \boldsymbol{S}_t \boldsymbol{A}'_t \boldsymbol{\iota}_i)} \qquad \tilde{\phi}^g_{ij,t}(H) = \frac{\phi^g_{ij,t}(H)}{\sum_{j=1}^{k} \phi^g_{ij,t}(H)}$$

with $\sum_{j=1}^{k} \tilde{\phi}^g_{ij,t}(H) = 1$, $\sum_{i,j=1}^{k} \tilde{\phi}^g_{ij,t}(H) = k$, and $\boldsymbol{\iota}_i$ corresponds to a selection vector with unity on the $i$th position and zero otherwise.

Based upon the GFEVD, Diebold and Yılmaz (2009, 2012, 2014) derived their connectedness measures

[3]Since the detailed algorithm of the TVP-VAR model with heteroscedastic variance-covariances is beyond the scope of this study interested readers are referred to Koop and Korobilis (2013) and Koop and Korobilis (2014)

[4]Furthermore, we want to stress out that even though we are talking about the spillovers of shocks we are well aware that those interpretation differs from the macroeconomic literature, however, with this interpretation we are just following the interpretations Diebold and Yılmaz (2009, 2012, 2014) to be in-line with the connectedness literature.

which are mathematically formulated as follows:

$$TO_{jt} = \sum_{i=1, i\neq j}^{k} \tilde{\phi}^{g}_{ij,t}(H) \tag{9}$$

$$FROM_{jt} = \sum_{j=1, i\neq j}^{k} \tilde{\phi}^{g}_{ij,t}(H) \tag{10}$$

$$NET_{jt} = TO_{jt} - FROM_{jt} \tag{11}$$

$$TCI_t(H) = k^{-1} \sum_{j=1}^{k} TO_{jt} \equiv k^{-1} \sum_{j=1}^{k} FROM_{jt}. \tag{12}$$

$$NPDC_{ij,t} = \tilde{\phi}_{ji,t}(H) - \tilde{\phi}_{ij,t}(H) \tag{13}$$

As mentioned previously $\tilde{\phi}^{g}_{ij,t}(H)$ illustrates the impact a shock in variable $j$ has on variable $i$. Hence, Equation (9) represents the aggregated impact a shock in variable $j$ has on all *other* variables which is defined as the *total directional connectedness to others* whereas Equation (10) illustrates the aggregated influence all *other* variables have on variable $j$ that is defined as the *total directional connectedness from others*.

Equation (11): Subtracting the impact variable $j$ has on others by the influence *others* have on variable $j$ results in the *net total directional connectedness* which provides us with information whether a variable is a net transmitter or a net receiver of shocks. Variable $j$ is a net transmitter (*receiver*) of shocks – and hence driving (*driven by*) the network – when the impact variable $j$ has on others is larger (*smaller*) than the influence all others have on variable $j$, $NET_{jt} > 0$ ($NET_{jt} < 0$). Another essential measure is given by Equation (12) the *total connectedness index ($TCI_t$)* which represents the average impact one variable has on all *others*. If this measure is relatively high it implies that the interconnectedness of the network and hence the market risk is high since a shock in one variable will influence others whereas a low value shows that most variables are rather independent from each other which in turn means that a shock in one variable won't cause other variables to adjust resulting in low market risk.

Since all aforementioned measures offer information on an aggregated basis, Equation (13) tells us more about the bilateral relationship between variable $j$ and $i$. The so-called *net pairwise directional connectedness ($NPDC_{ij,t}$)* exhibits whether variable $i$ is driving variable $j$ or vice versa. Therefore, we subtract the impact variable $i$ has on variable $j$ by the influence variable $j$ has on variable $i$. If $NPDC_{ij,t} > 0$ ($NPDC_{ij,t} < 0$), it means that variable $i$ is dominating (dominated by) variable $j$.

With respect to our application about the cross-currency basis swaps market, this methodology provides information about the market integration and consequently its implied risk. In addition, we analyze which CCSs are the net transmitters/receivers of shocks and hence whether they are driving or be driven by the network. What is more, the employed method illustrates which variables are dominating others on the bidirectional level. Those findings offer detailed insights in the dynamics of the CCS market which are essential for risk and asset management.

# 4 Empirical Results and Discussion

In this section, we present the main findings of the study and further elaborate on the main arguments that emerge from the analysis. Given that this study is primarily concerned with cross-country interrelations; the exposition of the relevant findings mainly dwells upon pairwise connectedness results. Nonetheless, in the interest of a balanced presentation, we further include in our analysis, both the evolution of the TCI over time and the respective total net connectedness figures.

## 4.1 Average and Dynamic Total Connectedness Measures

We begin our analysis by presenting averaged connectedness measures. Results are given in Table 2. It should be noted that the main diagonal of Table 2 reflects responses to idiosyncratic shocks, while, off-diagonal elements represent the interaction across the bases of the various cross-currency swaps against USD. More particularly, EUR, CHF, GBP, DKK and JPY appear to be the primary transmitters of shocks; whereas the main receivers of shocks within the network are NZD and CAD, followed by AUD, NOK and SEK. These results are more or less in line with what could be expected.

Market participants tend to be more influenced by developments in major funding markets (e.g. the Eurozone and Japan) than in relatively small markets (e.g. New Zeeland and Norway)[5]. However, there are also some interesting observations: such as the high ranking of CHF and DKK as transmitters and the role of AUD as a receiver (we will return to these later).

[Insert Table 2 around here]

The TCI value that is also included in Table 2, is indicative of the fact that comovements within this particular system of variables are rather moderate, as they constitute 36.53% of the total forecast error variance of the network. To be more precise, on average, 36.53% of the forecast error variance in one cross-currency basis can be attributed to the innovations in all others.

However, results reported in Table 2 are aggregate results that consider the period of study in its entirety; that is, without emphasizing specific economic or political events that may have resulted in considerable deviations from the average TCI value which is reported above. In this regard, to identify specific episodes that affected connectedness across bases over time, we proceed with the dynamic approach presented in the previous section. The results are illustrated in Figure 4.

[Insert Figure 4 around here]

Interestingly enough, we note that the dynamic connectedness of our network fluctuates considerably in over time, which is suggestive of the fact that connectedness across the various bases is highly responsive to events associated with the markets and currencies of interest. A closer look at Figure 4 reveals that pronounced connectedness is evident towards the end of 2008, the mid-2010 and late 2011, as well as, more

[5] In terms of global FX turnover, the currencies are ranked as follows: USD, EUR, JPY, GBP, AUD, CAD, CHF, SEK, NZD, NOK and DKK (BIS, 2016).

recently towards the middle of 2016 and late 2018. All of these periods can be linked to specific events that have been documented in the recent literature on CIP-deviations, namely the collapse of Lehman Brothers, the Eurozone debt crisis, and latest period including the MMMF reform and the search to solve the 'CIP puzzle'.

It would be instructive at this point to emphasize that, large connectedness values are suggestive of strong comovements across the network of interest. Within the specific framework of our analysis, this practically implies that when connectedness assumes large values then, there is a pronounced shortage of USD in the global economy that affects most of the currencies in our network. Therefore, increased levels of connectedness could be associated with periods when market confidence usually wanes and borrowing premia tend to soar.

On a final note, considering the evolution of the index over time that is illustrated in Figure 4, we cannot discern any notable structural breaks. To put differently, throughout the study there occur events that result in peak connectedness values; however, there is not one single point in time which marks a persistent change in the behaviour/direction of the index. Thus, events may act to trigger a significant increase (e.g. Bear Sterns, Lehman Brothers, Greece) or a decrease (e.g. central bank liquidity injections, the Federal Reserve FX swap network) in connectedness values. At the outset, however, the G10 cross-currency basis swap market remains highly connected through the role US dollar as a global reserve and funding currency.

## 4.2 Net Total Connectedness

In turn, we focus on the net total connectedness of the system which is presented in Figure 5. Net total connectedness practically shows the difference between the transmitting and the receiving end of each cross-currency basis considering the entire network. Note that blue-shaded areas correspond to periods when a particular basis assumes a net-transmitting role, while yellow-shaded areas, to periods when the basis receives, on net terms, from others. It follows that black-shaded areas correspond to periods when shocks overlap.

[Insert Figure 5 around here]

Even though all USD cross-currency bases of the sample may assume either a net-transmitting or a net-receiving role; it is evident that some of those attain just one unique position throughout the sample period. To be more explicit, the USD/EUR-basis is persistently transmitting to others, while, all of the bases on AUD, CAD, NOK, NZD and SEK swaps – with perhaps one or two short-lived exceptions – they seem to assume a persistent net-receiving role mainly. On general principles, net-receiving premiums can be associated with periods when the underlying currency has not been a significant driver of developments in the global USD cross-currency funding market.

For instance, the short-term wholesale funding by Swedish banks is typically done in US dollars or euros, rather than in Swedish kronor (Hilander, 2014). At the same time, the major Swedish banks were perceived to be relatively safe compared to their peers in London and New York during the 2007-08 financial crisis. Consequently, it is only logical that US dollar funding shocks are transmitted to, rather than from, the USD/SEK cross-currency basis swap market. Furthermore, as can be seen from Figure 2, USD/AUD and USD/NZD stand out by generally having had a positive rather than negative cross-currency basis. As outlined in detail by Sushko et al. (2016) and Borio et al. (2016), although most G10 banking systems have significant US dollar funding gaps, there are also exceptions such as Australia and New Zeeland. Thus, these are not only less connected to other cross-currency basis swap markets but also less likely to influence the cost of US dollar funding in other jurisdictions. In addition, as has been well documented, some banking systems (notably Canada) were in relatively good shape and managed to withstand the 2007-08 financial crisis and US dollar funding constraints that followed (see, for instance, Terajima et al., 2010). Consequently, despite Canada's geographic and economic proximity to the US, USD/CAD cross-currency basis swaps did not evolve into a market, which transmitted shocks to other G10 currency pairs. To sum up, although it would be tempting to conclude that smaller markets are more likely to be net-receivers rather than net-transmitters of shocks in the global cross-currency basis swap market, the reality is considerably more nuanced.

Indeed, USD/CHF, USD/DKK, USD/GBP and USD/JPY can be either net-transmitters or net-receivers depending on the specific point in time. What is more, it is worth noting that irrespective of whether a particular currency pair is a net-transmitter or a net-receiver of shocks in the cross-currency basis swap market, the very fact that, throughout the study, there exist either net-transmitting or net-receiving conditions, is further evidence of the persistent character of CIP-deviations. This is in line with the argument proposed by this study that CIP-deviations should not necessarily be seen as opportunities that will be arbitraged away. To attain a better understanding of the findings presented in Figure 5, we need to elaborate on specific developments that occurred in the financial system in recent years.

To begin with, the euro is the second most traded currency in the world, lagging only behind the US dollar, while since its formal introduction in 2002, the common currency has not only been important for international trade but has also been used as an official reserve currency. More importantly, the Eurozone banking system has faced significant US dollar funding gaps throughout the period studied (Avdjiev et al., 2019; Sushko et al., 2016). Therefore, it is no surprise that developments in the USD/EUR cross-currency basis swap market can be a significant source of shocks for all G10 currency pairs. Hence, through the connectedness of the markets, US dollar funding shortages reflected in USD/EUR swaps will affect US borrowing costs in other markets as well.

In turn, the USD/CHF basis appears to be receiving during the period 2011-2014; that is, throughout the period when the Swiss franc was pegged to the euro (i.e., before eventually decoupling from the euro in January 2015). This finding is a clear indication of the dependency of the franc on the euro, and also of the fact that USD/CHF was not driving developments in the cross-currency basis swap market during that period. The Danish krone is another example of a currency that is pegged to the euro. The difference between the Danish krone and the Swiss franc is that the former has been continuously pegged to the euro (since 1999) in line with the regulations stipulated by the Exchange Rate Mechanism and the Eurozone (ERM-II). Initially, USD/DKK was influenced by the 2007-08 financial crisis (i.e., assuming a net-receiving position), while later on, in the years that followed, it assumed a net-transmitting position until early 2015, before reverting to its net-receiving position. USD/DKK is not only the least traded currency pair in our study but also the one displaying the most extensive deviations from the CIP. This makes it an interesting case. One the one hand, by not being classified as a safe haven at the outset, the Danish (and other Nordic) market absorbed shocks during the 2007-08 financial crisis. On the other hand, by being pegged to the euro and receiving a safe haven status within the 'extended' euro area during the Eurozone sovereign debt crisis, USD/DKK joined USD/EUR in transmitting shocks to others until the crisis receded[6].

Another instance, where a specific basis assumes both roles, arises when we focus on the USD/JPY market. In particular, USD/JPY cross-currency basis swaps appear to be receiving for most of the period between 2009 and mid-2010, as well as, between the period mid-2016 to the end of the sample. The prior period is consistent with the perception of Japan as a relative safe haven at the time (Stenfors, 2019). The funding pressures facing Japanese banks were less severe than their peers in the US and Western Europe. The following period, on the other hand, follows a well-documented episode, where the USD/JPY cross-currency basis (and several others) turned sharply negative. This largely stemmed from the expansion of the 'big three' Japanese banks abroad and there resulting US funding gaps (Shabani et al., 2016), and coincided with the MMMF reform in 2016.

USD/GBP cross-currency basis swaps act as net-receivers during most of the period between 2012 and 2016, suggesting that developments in markets outside the UK during that period played a key role and proved to be more crucial in shaping basis dynamics across markets. Turning to the cross-currency basis swaps that persistently assume a net-receiving role, none of them involve typical safe-haven currencies and in this regard, we would neither expect them to drive developments in the foreign exchange market nor to assume a robust net-transmitting position in the cross-currency US dollar funding market – unless they are undergoing a domestically driven crisis.

### 4.3 Net Pairwise Connectedness

However enlightening the net total approach may be, it still has its drawbacks as total figures inevitably mask interesting stories between specific variables of the system. That is, even though net total figures provide a clear picture of the position of the variables of the network over time, they fail to concentrate on pairs of variables and to identify the corresponding dynamics.

[Insert Figures 6-8 around here]

In this respect, in this section, we present bilateral outcomes and purport to investigate the specific interrelations between the currencies of interest. Net pairwise connectedness outcomes are given in

[6] For a detailed analysis of the Danish krone during the Eurozone sovereign debt crisis, see Jørgensen et al. (2016).

Figures 6-8. Furthermore, for the sake of brevity, analysis in this section will offer a general comment regarding the pairwise evolution of the relevant cross-currency bases; however, without neglecting any specific episodes between currencies that provide useful insights and increase our understanding of the underlying interrelations.

Starting with the Eurozone, USD/EUR cross-currency basis swaps have generally affected bases of other currency pairs throughout the period of analysis. This finding is also in line with the results presented in the previous section. At the same time, however, the USD/JPY basis transmitted intensively to the USD/EUR markets towards the end of 2015 and until mid-2016. Other instances where USD/EUR cross-currency basis swaps receive noteworthy influence from others include the USD/GBP both in late 2014 and mid-2016, as well as, the USD/CHF at the beginning of 2016.

Another interesting element in our analysis that deserves further attention relates to periods where decoupling is evident. An example of decoupling can be seen in the panel that presents the connectedness level between USD/EUR and both the USD/AUD and the USD/CAD cross-currency basis swap markets. Evidently, in the years that followed 2013, connectedness between the Eurozone on the one and Australia and Canada on the other shifted from higher to negligible levels. The significant connectedness during the Eurozone crisis illustrates how market participants transmit US dollar funding shocks to other banking systems via the cross-currency basis swap market. However, it also shows that some 'normality' may be restored in those markets, which arguably ought to be more immune to crises in other regions.

Turning to the USD/JPY basis, this also appears to receive US funding shortage shocks considerably on net terms, at different periods from (i) USD/CHF; between 2009-2012 and from mid-2016 onwards, (ii) USD/GBP; from early sample period until mid-2011 and also from mid-2016 onwards, (iii) USD/NOK; especially in the years that followed 2015, as well as (iv), USD/DKK; especially in the years between 2011 and 2014.

Given the size of the UK banking sector, it is no surprise that the USD/GBP cross-currency basis swap market has been a significant transmitter of US dollar funding shortages for most of the period under investigation. However, the market has also received influence mainly from USD/CHF (i.e., for almost the entire period under investigation), from the USD/SEK (i.e., especially between 2011 and early 2013), as well as, from the USD/DKK (i.e., particularly, between 2011 and 2014). The fact that the USD/CHF market transmits US funding shortages to the USD/GBP market is interesting as it highlights the critical position of the Swiss franc as a safe-haven currency.

Pairwise connectedness in relation to bases on both USD/AUD and USD/CAD swaps is also insightful and in line with previously reported results regarding the decoupling of these markets that is rather evident in the years that followed 2013. More particularly, both markets, despite that they clearly undergo some periods in which they receive US funding shortage shocks from other markets (e.g., USD/CHF, USD/SEK and USD/DKK); they eventually tend to reach very low (i.e., negligible) levels for most of the period between 2013 and the remainder of our sample.

Turning to the Swiss franc, we have already mentioned the prominent position of the currency as a safe haven. We have also mentioned that the USD/CHF basis affects both USD/JPY and USD/GBP; however, they are receivers of US funding shortage shocks from the USD/EUR market. Connectedness between USD/CHF and USD/EUR could explain the fact that the Danish krone (which is pegged to the euro) market has periods when it assumes a net transmitting role vis-a-vis the Swiss market. Further, considering the USD/DKK market, what is also evident in Figure 5 is that it acts mainly as a net transmitter of shocks against both the USD/SEK and the USD/NOK markets.

Overall, pairwise connectedness results are indicative of the fact that US dollar funding shortage shocks may very well have more than just a couple of sources, while most cross-currency swap markets under investigation, may act as both, depending on the period and the underlying dynamics of the economy and the banking sector.

## 5 Concluding Remarks

In this study, we focus on CIP-deviations to highlight their role in increased levels of stress in international financial markets. Our approach is based on the premise that given the rather permanent nature of the violations of CIP conditions, they are more likely than not to constitute a separate market of their own. To be more specific, risk premia relating to CIP-deviations may very well be determined by some price mechanism that receives feedback from and is subject to various sources of risk. In this regard, by considering the CIP-deviations that occur in the cross-currency basis swap market, we provide new evidence in connection with contagion dynamics within this particular market for risk premia.

To accomplish the objectives of our study, we consider a cross-country framework of analysis, which includes all G10 currencies against the US dollar and covers the period from 2007 to 2018. We further employ a TVP-VAR empirical approach to measure connectedness across the different cross-currency bases that transpire in the markets included in our study. The TVP aspect of our method of choice implies that it practically constitutes an extension of the standard Diebold and Yılmaz (2012, 2014) approach as it does not suffer from the deficiencies of the typical rolling-windows method and thus provides refined measurements of connectedness.

Our findings indicate that total network connectedness across cross-currency bases is mainly event-dependent, and this can be evidenced by the significant fluctuations of the respective index that occur over time. Furthermore, when we consider net connectedness across the network of the variables included in our study, we note that the USD/EUR-basis appears to be a persistent transmitter of shocks to other bases, while all of the bases linked to AUD, CAD, NOK, NZD and SEK assume a net receiving role for the most of the period. In addition, cross-currency basis swaps between USD and CHF, DKK, GBP and JPY can act either as net transmitters or net receivers depending on the period. A closer investigation of these findings reveals that the cost of US dollar funding within the countries is being determined by the bases on currencies whose underlying banking sector has undergone considerable US dollar funding gaps over the years (e.g., the Eurozone banking system or the Japanese system following the recent expansion by the so-called 'big three' banks). It is also evident that the role of currencies, such as the CHF and the DKK, either as net-transmitters or net-receivers, is determined by the very fact that these currencies were pegged to the EUR during the unravelling of significant financial developments in international markets.

When we consider the findings of the study from a net pairwise point of view, we find evidence of decoupling (i.e., considerably lower levels of connectedness from one point onward) between pairs of bases on specific currencies (e.g., between USD/EUR and USD/AUD after 2013). The latter could be indicative of the fact that relatively stable times for international financial markets may also be reflected upon the negligible levels of US dollar funding shocks that are being transmitted between bases pairs. We also find that safe haven currencies appear to have a net-transmitting role.

Overall, our findings suggest that beneath the persistent CIP-deviations lie dynamics that go beyond standard economic analysis of fundamentals. Through the cross-currency basis swap market, CIP-deviations can be 'bought and sold' like assets in other markets (Stenfors, 2019). As such, market participants are influenced by developments in other cross-currency basis swap markets, as these provide indications with regards to the direction of the price in the future. In this regard, we provide evidence in connection with contagion within the global market for cross-currency basis swaps - and highlight how these differ across regions and over time.

The findings can also be read from a policymaking perspective. Money market risk premia indicate a disturbance within the first stage of the monetary transmission mechanism. A CIP-deviation, in this respect, brings another dimension to stress as it involves two currencies and two central banks. Our study takes this argument further and emphasises the importance of the network of current and expected future risk premia for a range of currency pairs, which transmit and receive shocks to each other. Put simply, for monetary policy to be effective within the increasingly international financial markets, the decisions of other central banks have become increasingly critical. However, this also includes the behaviour of financial market participants - even those involved in seemingly unrelated financial markets.

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Table 1: Summary Statistics

| | Mean | Median | Max | Min | Std.Dev. | Skewness | Kurtosis | Jarque-Bera | $Q(20)$ | $Q^2(20)$ | ERS | Obs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EUR | -0.011 | 0.000 | 25.000 | -23.000 | 2.196 | 0.429*** | 40.590*** | 169003.6*** | 419.6*** | 4068.1*** | -27.253*** | 2869 |
| JPY | -0.015 | 0.000 | 20.000 | -24.750 | 1.944 | 0.0545 *** | 32.916*** | 106985.1*** | 232.8*** | 1342.2*** | -24.447*** | 2869 |
| GBP | -0.004 | 0.000 | 27.000 | -26.500 | 1.672 | 0.243*** | 86.010*** | 823753.1*** | 471.7*** | 1637.0*** | -23.864*** | 2869 |
| AUD | 0.001 | 0.000 | 30.000 | -33.000 | 1.424 | -0.151*** | 206.407*** | 4945997.9*** | 245.2*** | 1686.2*** | -26.637*** | 2869 |
| CAD | -0.011 | 0.000 | 19.000 | -20.000 | 1.375 | -1.563*** | 81.066*** | 729692.9*** | 132.5*** | 1684.5*** | -22.962*** | 2869 |
| CHF | -0.011 | 0.000 | 28.000 | -27.500 | 2.223 | 0.332*** | 42.076*** | 182584.6*** | 107.9*** | 520.1*** | -25.589*** | 2869 |
| SEK | -0.006 | 0.000 | 12.000 | -19.000 | 1.453 | -2.120*** | 41.673*** | 180938.2*** | 138.8*** | 372.6*** | -23.553*** | 2869 |
| NZD | 0.003 | 0.000 | 13.250 | -14.000 | 0.861 | 0.378*** | 71.747*** | 565032.4*** | 58.5*** | 241.9*** | -14.578*** | 2869 |
| NOK | -0.006 | 0.000 | 23.000 | -19.500 | 1.402 | -0.794*** | 90.551*** | 916604.2*** | 132.1*** | 328.8*** | -21.314*** | 2869 |
| DKK | -0.015 | 0.000 | 35.000 | -60.000 | 2.630 | -3.642*** | 137.667*** | 2174261.0*** | 88.3*** | 423.6*** | -25.268*** | 2869 |

Notes: ***,**,* denote significance level at 1%, 5% and 10%; Skewness: D'Agostino (1970) test; Kurtosis: Anscombe and Glynn (1983) test; JB: Jarque and Bera (1980) normality test; ERS: Stock et al. (1996) unit-root test; $Q(20)$ and $Q^2(20)$: Fisher and Gallagher (2012) weighted portmanteau test.

Table 2: Averaged Connectedness Measures

| | EUR | JPY | GBP | AUD | CAD | CHF | SEK | NZD | NOK | DKK | FROM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EUR | 46.142 | 9.019 | 10.034 | 0.910 | 1.088 | 10.228 | 6.221 | 0.765 | 5.201 | 10.391 | 53.858 |
| JPY | 11.856 | 56.878 | 7.210 | 1.487 | 1.164 | 7.340 | 4.016 | 0.622 | 4.028 | 5.399 | 43.122 |
| GBP | 12.318 | 6.992 | 54.247 | 0.903 | 1.641 | 7.814 | 5.212 | 0.530 | 4.604 | 5.739 | 45.753 |
| AUD | 2.859 | 2.657 | 2.249 | 82.590 | 0.972 | 1.946 | 1.557 | 1.177 | 1.580 | 2.412 | 17.410 |
| CAD | 2.729 | 2.343 | 3.222 | 1.079 | 83.475 | 2.017 | 1.293 | 0.962 | 1.266 | 1.615 | 16.525 |
| CHF | 12.367 | 6.859 | 7.442 | 0.876 | 0.800 | 54.630 | 4.226 | 0.924 | 5.636 | 6.241 | 45.370 |
| SEK | 10.198 | 4.941 | 6.376 | 0.783 | 0.699 | 5.649 | 57.282 | 0.555 | 6.521 | 6.996 | 42.718 |
| NZD | 1.979 | 1.064 | 1.612 | 1.712 | 0.972 | 2.193 | 1.243 | 85.801 | 2.093 | 1.332 | 14.199 |
| NOK | 8.583 | 4.493 | 5.265 | 1.059 | 0.578 | 6.738 | 6.999 | 0.962 | 59.521 | 5.801 | 40.479 |
| DKK | 14.293 | 5.386 | 6.457 | 0.675 | 0.588 | 6.527 | 6.012 | 0.748 | 5.160 | 54.154 | 45.846 |
| Contribution TO others | 77.182 | 43.755 | 49.868 | 9.484 | 8.500 | 50.453 | 36.778 | 7.245 | 36.088 | 45.928 | 365.280 |
| NET spillovers | 23.323 | 0.633 | 4.115 | -7.925 | -8.024 | 5.082 | -5.940 | -6.955 | -4.391 | 0.082 | TCI |
| NPDC transmitter | 9 | 5 | 7 | 2 | 1 | 8 | 4 | 0 | 3 | 6 | 36.528 |

Notes: Results are based on a TVP-VAR model with lag length of order one (BIC) and a 10-step-ahead generalized forecast error variance decomposition.

Figure 1: USD/JPY Cross-Currency Basis Swap, 1997-2007

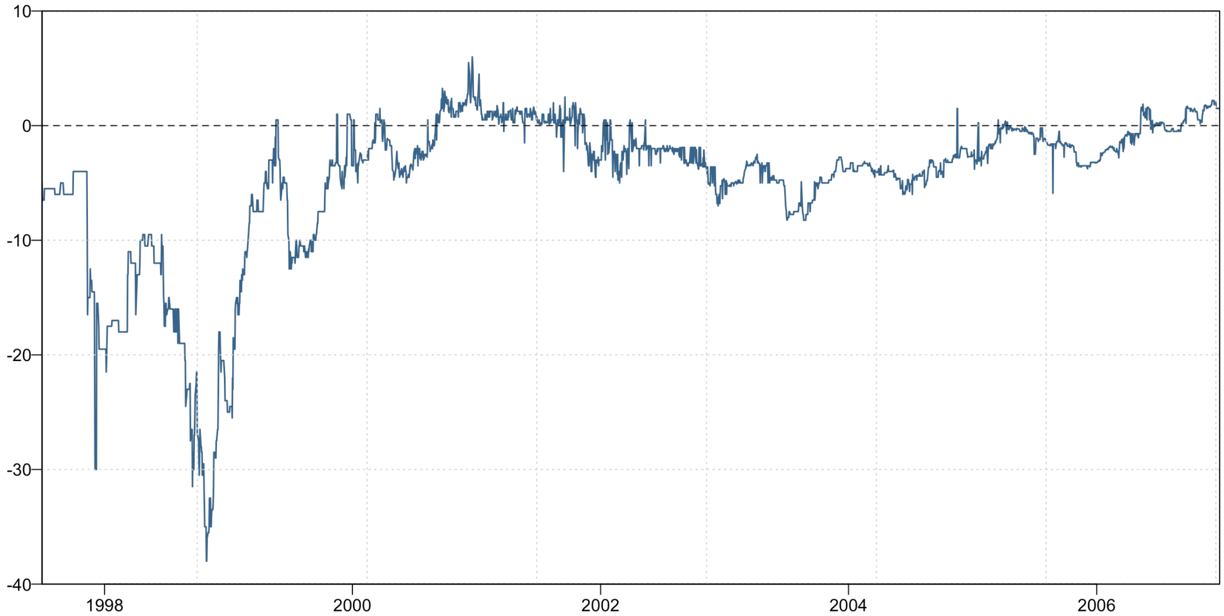


Figure 2: Cross-Currency Basis Swaps

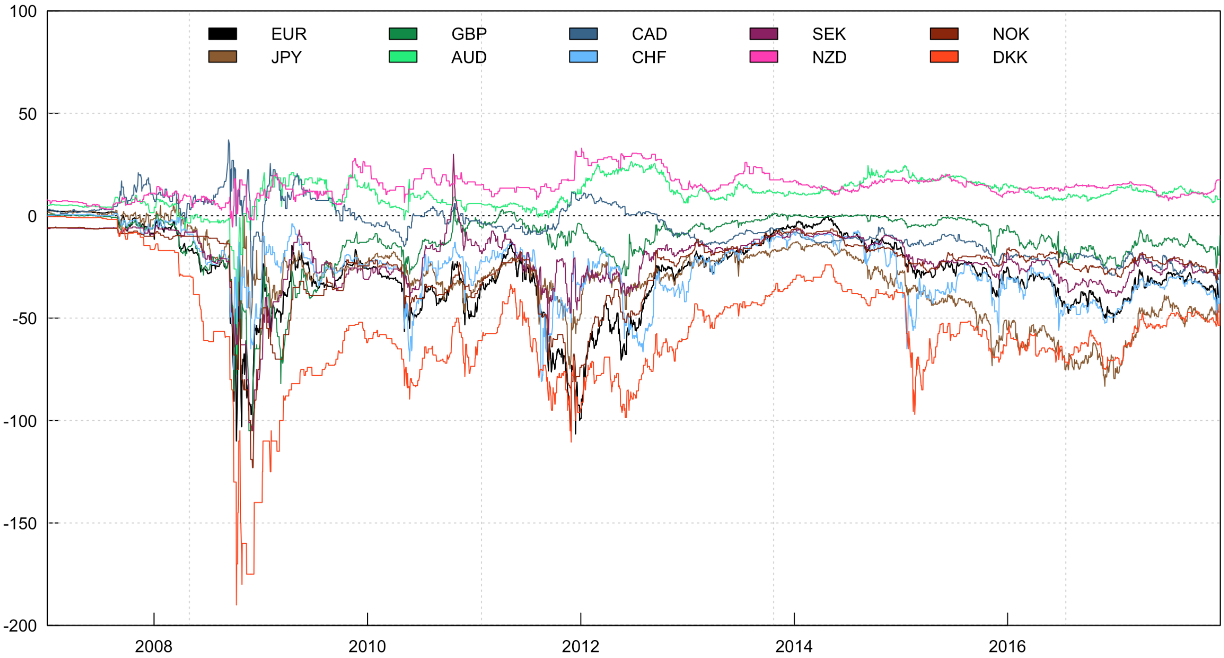



Figure 3: First Differenced Cross-Currency Basis Swaps

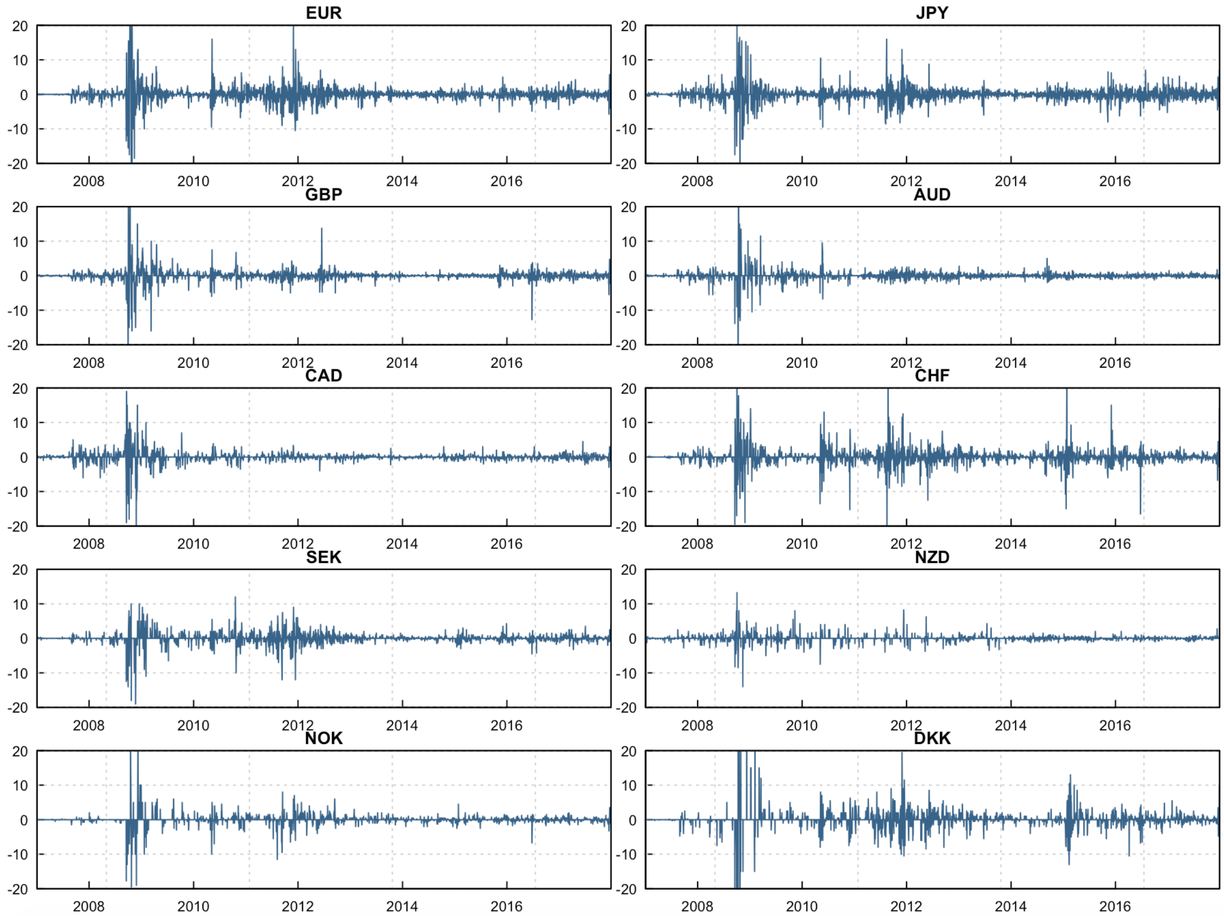
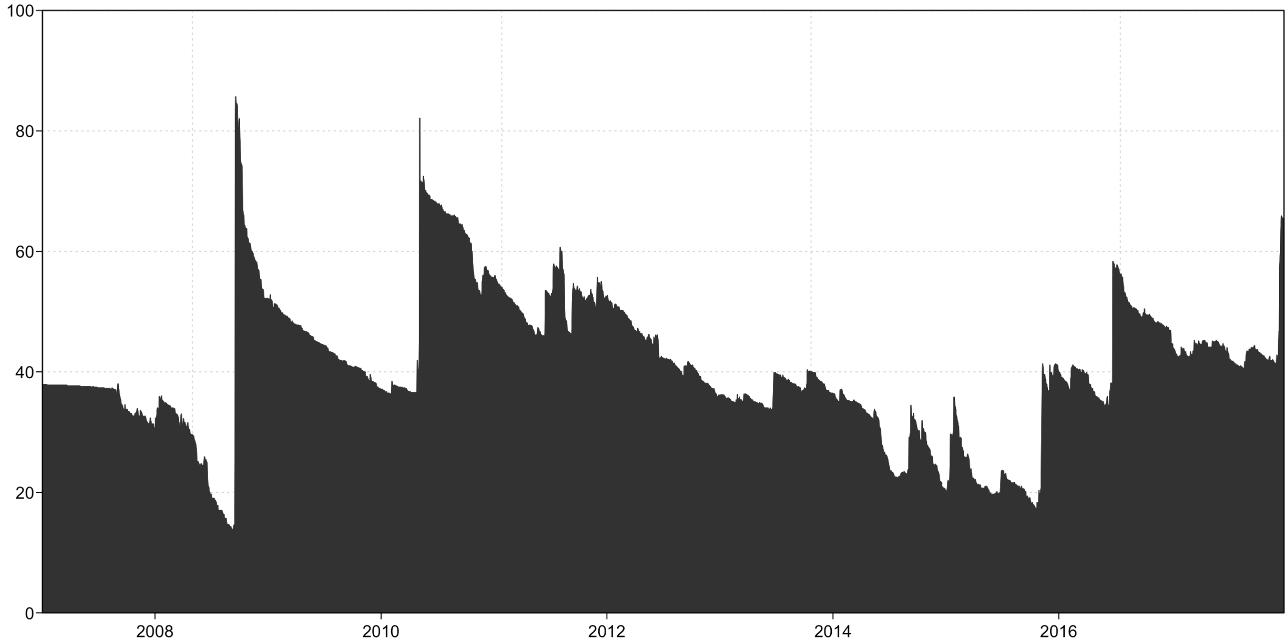
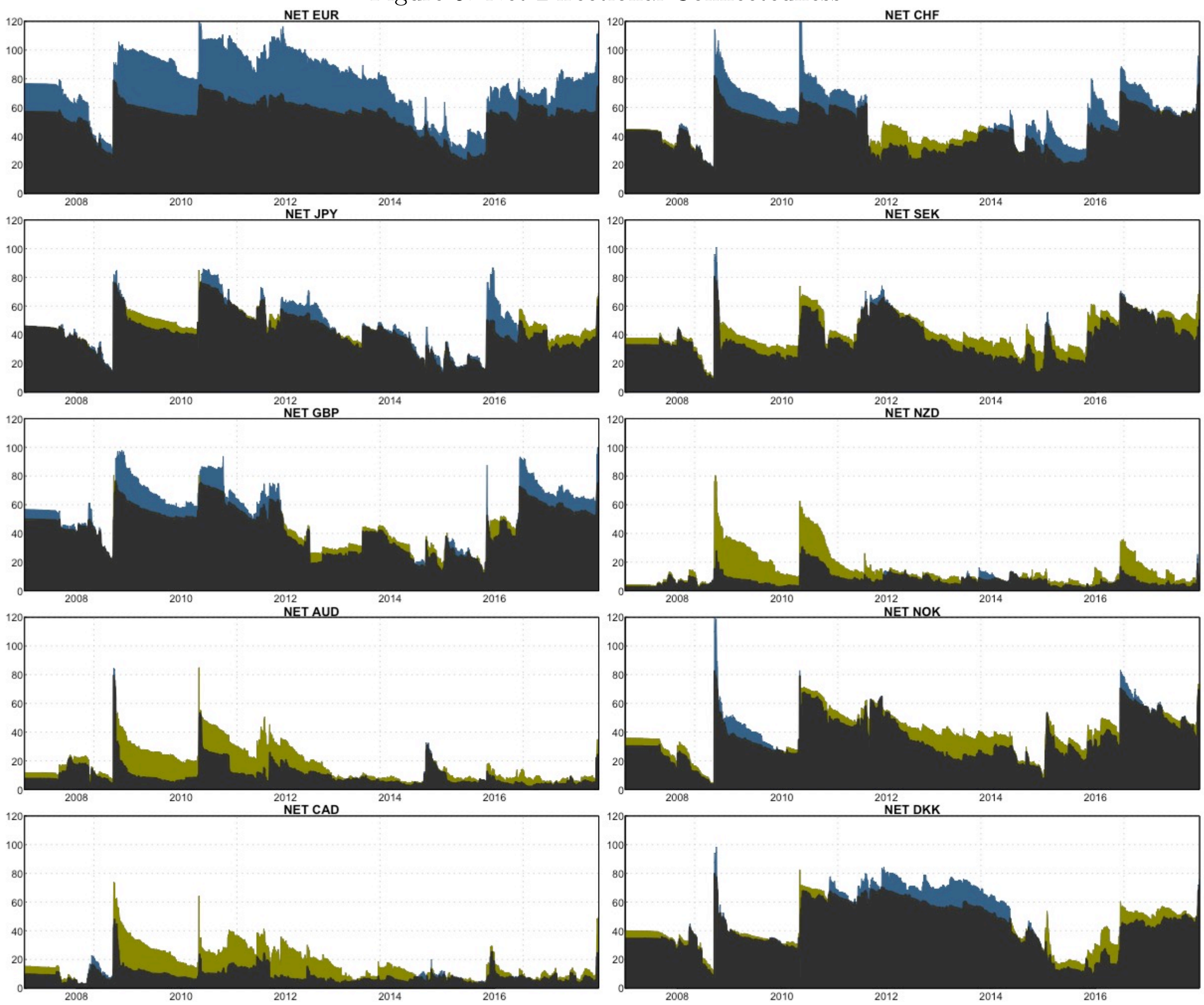


Figure 4: Dynamic Total Connectedness



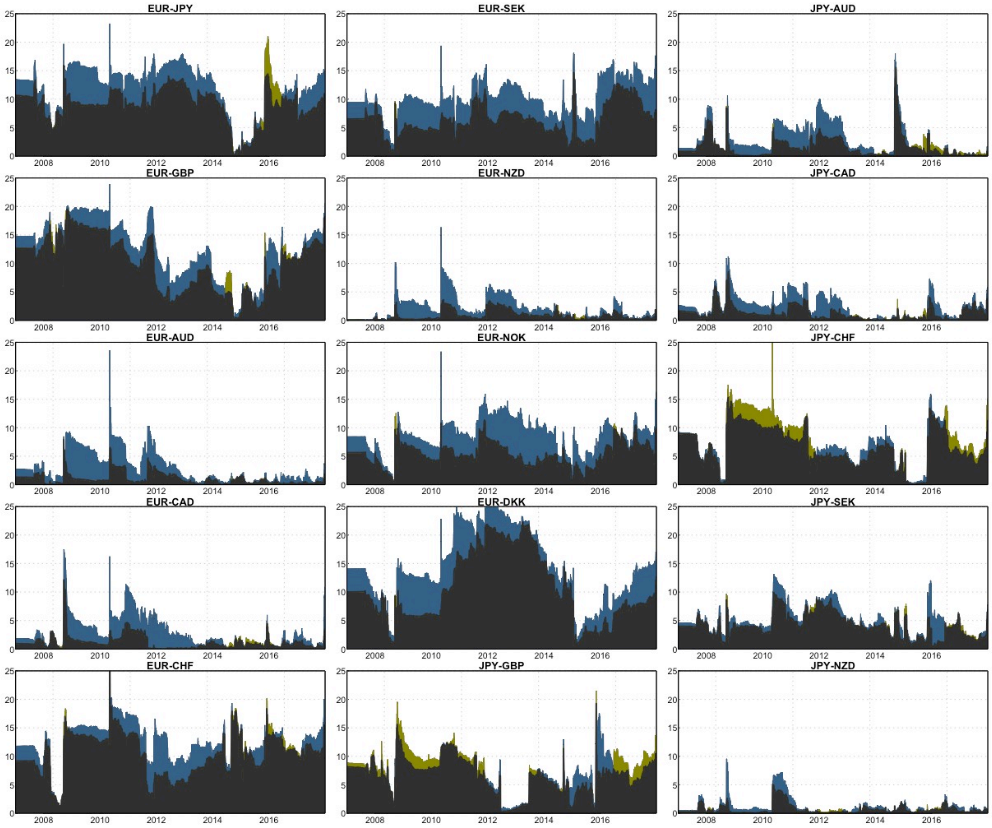

Notes: Results are based on a TVP-VAR model with lag length of order one (BIC) and a 10-step-ahead generalized forecast error variance decomposition.

Figure 5: Net Directional Connectedness



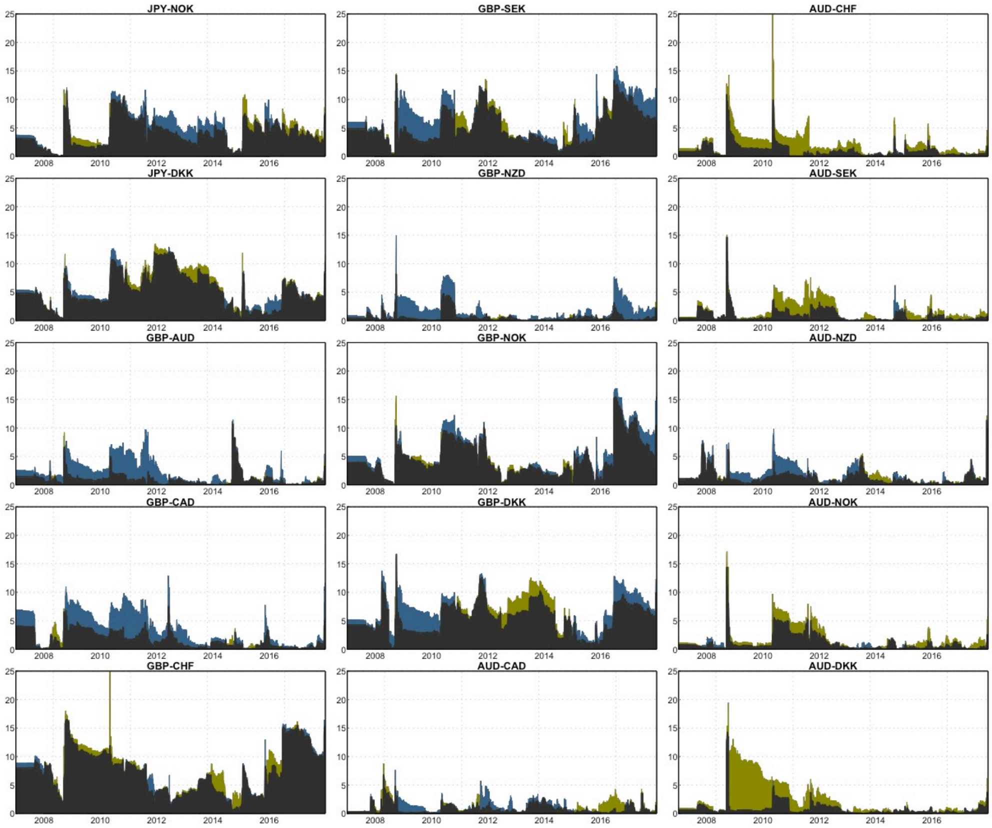

Notes: The black areas represent the overlap of the dynamic directional connectedness variable $i$ transmits TO and receives FROM $j$. A positive net connectedness is marked blue whereas a negative net total connectedness is marked yellow.

Figure 6: Net Pairwise Directional Connectedness (I)



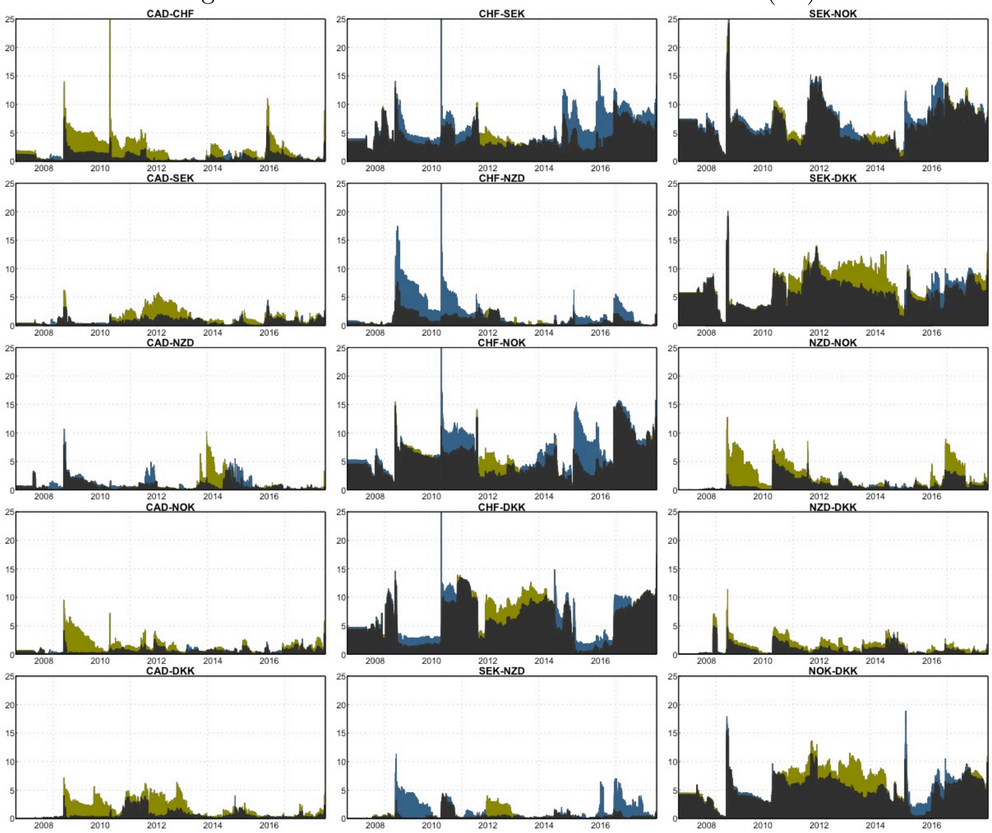

Notes: The black areas represent the overlap of the dynamic pairwise directional connectedness variable $i$ transmits TO and receives FROM $j$. A positive net pairwise connectedness is marked blue whereas a negative net pairwise connectedness is marked yellow.

Figure 7: Net Pairwise Directional Connectedness (II)




Notes: The black areas represent the overlap of the dynamic pairwise directional connectedness variable $i$ transmits TO and receives FROM $j$. A positive net pairwise connectedness is marked blue whereas a negative net pairwise connectedness is marked yellow.

Figure 8: Net Pairwise Directional Connectedness (III)




Notes: The black areas represent the overlap of the dynamic pairwise directional connectedness variable $i$ transmits TO and receives FROM $j$. A positive net pairwise connectedness is marked blue whereas a negative net pairwise connectedness is marked yellow.