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Independent Policy, Dependent Outcomes: A Game of Cross-Country Dominoes across European Yield Curves

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Abstract

This study investigates the dynamic transmission mechanism between 2Y, 5Y and 10Y interest rate swaps (IRS) for six European currencies (CHF, DKK, EUR, GBP, NOK and SEK) from August 6, 1999 to March 4, 2021 applying the time-varying parameter vector autoregressive connectedness approach in the spirit of Antonakakis et al. (2020). Furthermore, the connectedness approach (Diebold and Yılmaz, 2012, 2014) is extended to allow analyzing aggregated and conditional connectedness measures which improve their interpretability and obtain more in-depth information concerning the cross-maturity/cross-currency propagation mechanism. We document that EUR and DKK have been the most prominent transmitters of shocks in the network. We also find that the 10Y IRS has increasingly assumed a net-transmitting role at the expense of the 2Y IRS – in line with a shift towards unconventional monetary policy and quantitative easing. From a policymaking perspective, this implies means that the role of the domestic short-term interest rate has lost relevance for the monetary transmission mechanism at the expense of the foreign long-term interest rate.

Keywords: Dynamic Connectedness; Aggregated Connectedness, Conditional Connectednes; Interest Rate Swaps; TVP-VAR; Yield Curves.

JEL codes: C32; C5; F3; G15.

1 Introduction

The global fixed income market is extremely connected compared to other asset markets. The connectedness has, in particular, an international and a maturity-related dimension. Influential work by Ilmanen (1995) show that expected excess returns for long-term bonds issued by G7 countries are highly correlated. Similar findings are documented by Sutton (2000), who suggests that there is an international component that contributes to the correlation in term premia across markets and over time. Furthermore, authors have also noted that the correlation between term premia of G7 government bonds is time-varying but seems to have increased over time in line with the integration of international financial markets since the 1980s (see, in particular, Dahlquist and Hasseltoft, 2013). At the same time, co-movements appear to increase during episodes of high volatility and stress in the financial system, and the existence of bond market integration in different geographical regions (Johansson, 2008). This finding is supported by Gabauer et al. (2020b) who show that the Asia-Pacific bond market is highly integrated and that the degree of interconnectedness varies substantially over time reaching a peak during the Global Financial Crisis of 2007 (hereafter, GFC). Furthermore, this strand of literature – the examination of bond yields and interest rate spillovers – has gained popularity, see among others, (Cronin, 2014; Garcia-de Andoain and Kremer, 2017; Galariotis et al., 2018; Antonakakis et al., 2019b; Chatziantoniou et al., 2020; Chatziantoniou and Gabauer, 2021). The main implication from all these studies is that there is a dynamic element that has to be considered in the investigation of the interaction across financial variables (including bond yields) and that turbulent times can be crucial in drawing conclusions relevant for the markets under investigation.

From the perspective of financial market participants, the global and connected bond universe offers a wide range of hedging possibilities. It also has important implications for policymakers, as it suggests that a country's long term borrowing cost may be directly influenced by the buying and selling of other countries' bonds. In this respect, spillover shocks from major markets tend to be more pronounced. For instance, studying a range of emerging markets in Latin America, Asia and Eastern Europe between 1994 and 1999, Arora et al. (2000) find that sovereign bond spreads are positively influenced by the level of US fed funds rate.[1] Moreover, using a dataset covering the aftermath of the GFC, Rogers et al. (2018) find that US unconventional monetary policy easing shocks lowered not only domestic, but also UK, German and Japanese bond term premia.

The other crucial dimension of connectedness relates to the monetary transmission mechanism and the expectations hypothesis of the term structure of interest rates. Short-term market interest rates are mainly determined by the (expected) central bank policy rate for the corresponding maturity (see, for instance, Kuttner, 2001). However, changes in policy rates are rare, which results in a high level of "stickiness" across the short end of the yield curve (Stenfors, 2018). The ability of central banks to steer short-term interest rates not only explicitly, but also implicitly through frameworks of forward-guidance,

[1] US fed funds and T-bills may move in opposite direction.

adds another layer to yield curve dynamics. Indeed, Jotikasthira et al. (2015) observe that co-movements among international bonds largely stem from either central bank policy rates (the 'policy channel') or term premia (the 'risk compensation channel'). Although both are crucial, the importance of term premia becomes more important as the time to maturity increases, and the influence of conventional central bank policymaking diminishes. Kumar and Okimoto (2011) also find that international bond market integration is maturity-dependent. Investigating G7 bond markets over two decades leading up to the GFC, they report that the long-term bond market is considerably more integrated than the short-term.

With these observations in mind, we strongly believe that in order to attain a better understanding of the impact of interest rates on monetary policy and financial markets, it is important to identify two parallel dimensions; that is, cross-maturity interaction and cross-currency interaction. In turn, an appropriate framework of analysis would be to investigate the connectedness across networks that consist of either different currencies or different maturities or a combination of the two. Network connectedness would then emphasize not only total interaction across the system but also, the specific interaction between pairs of the variables involved. Therefore, in this paper, we investigate the time-varying transmission mechanism between yields in different currencies and maturities. Our study uses interest rate swap (IRS) yields for 2, 5 and 10-year maturities and includes the European G10 currencies (CHF, DKK, EUR, GBP, NOK and SEK) from 1999 to 2021.

Our approach differs from previous studies in several respects. First, central banks can influence short-term interest rates and, to some degree, long-term yields. However, unconventional monetary policy measures aimed at long-term yields may also influence the expectation of the future short-term central bank policy rate. We emphasise the importance of investigating the dynamic evolution of cross-maturity spillovers. Second, long-term yields may be influenced by equivalent maturities in other currencies. However, following the logic above, the relationship may also involve transmission of shocks from short-term yields in one currency to long-term yields in another – or vice versa. Hence, we also emphasise the importance of investigating not only the dynamic evolution of cross-currency spillovers, but in combination with cross-maturity spillovers. Third, we utilise the most sophisticated method to date in order to extract the relevant dynamic connectedness measures, and emphasise 'dynamic' because over time this spillover framework may differ, reflecting a changing macroeconomic environment and global economic events.

By doing so, our paper contributes to the literature, which hitherto has tended to treat international and maturity-related dimensions of yield curves as separate phenomena. For instance, Sutton (2000) identifies an international component to risk premia and notes that bond yields co-vary excessively between markets. However, the author does not consider the cross-maturity angle. Kumar and Okimoto (2011), on the other hand, emphasise decoupling of short-term policy rates from longer-term bond yields and the evolution of the international bond market integration. Nonetheless, they keep short and long maturities separated. Our paper is, perhaps, most relatable to Jotikasthira et al. (2015), who study the short- and long-term channels and also incorporate exogenous variables (e.g. inflation and industrial production). However, we do not include exogenous macroeconomic variables and, instead, focus on the network of interest rates per se. Most notably, our study is dynamic and considers the evolution of the cross-currency and cross-maturity relationships across time.

European financial markets have highly integrated for many decades. Except for Denmark (which pegs its currency to the euro), all central banks in our study are inflation-targeting regimes. However, all countries have – to various degrees – gradually moved towards forward-guidance and unconventional monetary policy such as quantitative easing to tackle stubbornly low inflation rates. Thus, from a policy perspective, our investigation addresses challenges in conducting monetary policy within an international and increasingly connected financial system and accounts for the increasing skepticism towards the role of the official central bank rate within the transmission of monetary policy. Indeed, our findings indicate that role of the domestic short-term interest rate has lost relevance for the monetary transmission mechanism at the expense of the foreign long-term interest rate in recent years.

The rest of the paper is structured as follows. Section 2 provides and overview of the data. Section 3 outlines the methodology in detail (with a technical extension included in the Appendix). The results are then presented in Section 4, followed by a concluding discussion and summary of the policy implications in Section 5.

2 Data

Our cross-country/cross-maturity study includes the six European G10 currencies, namely the Swiss franc (CHF), the Danish krone (DKK), the euro (EUR), the British pound (GBP), the Norwegian krone (NOK) and the Swedish krona (SEK) retrieved from *Bloomberg*. We use daily closing prices of 2-year, 5-year and 10-year interest rate swap (IRS) prices from August 6, 1999 to March 4, 2021.

We believe that the choice of benchmarks maturities (2Y, 5Y and 10Y) is the most appropriate for this study, as a solid representation of the short-, medium- and long-term market. For the smaller currencies, the liquidity rapidly deteriorates beyond 10Y, making 15Y, 20Y or 30Y unsuitable. Arguably, 1Y could be a good alternative for the short term. However, it is sticky and considerably more influenced by the prevailing central bank policy rate. In this respect, the 2Y IRS captures more of the (expected) monetary policy forward guidance.

In contrast to most related studies, we use IRS rather than bond prices for the benchmark maturities. This has two benefits.

First, credit spreads between different interest rate instruments tend to be volatile during turbulent periods. IRS prices are less influenced by country-specific characteristics, such as perceived credit risk (e.g. Italy) or safe-haven status (e.g. Germany), squeezes and other securities-related phenomena.

Second, the IRS market is highly liquid for the selected currencies, and in particular for the three benchmark maturities. According to BIS (2019b), the average total daily IRS turnover in the six currencies amounted to more than USD 730 billion in 2019. The approximate split was as follows: EUR (69%), GBP (22%), SEK (4%), NOK (3%), CHF (2%) and DKK (1%). Combined, they stood for around 98%

of the turnover in the European OTC interest rate derivatives market (BIS, 2019a).

Before moving to the methodology and results, however, let us briefly study the historical development of the 2Y, 5Y and 10Y IRSs of the six European G10 currencies. Figure 1 displays the 2Y IRS. As can be seen, the different currencies have tracked each other reasonably well during the economic and financial cycles over the last two decades. Notable episodes include the dot-com bubble and subsequent crash, the GFC, the Eurozone sovereign debt crisis, the low-interest environment that since has been prevalent, and the recent COVID-19 pandemic. The 2Y CHF IRS has consistently been the lowest. NOK, and GBP (between 2003 and 2007), have had the highest yield. Pegged to the common currency, the 2Y DKK IRS has tracked EUR very closely. However, so has SEK, despite Sweden having conducted an independent monetary policy throughout the period. The patterns for the 5Y and 10Y IRSs have been very similar. However, being less influenced by sudden shifts in central bank monetary policy, the six currencies have tracked each other more closely when studying medium- and long-term maturities.

[INSERT FIGURE 1 AROUND HERE]

In a next step, a brief description of the summary statistics illustrated in Table 1 is provided. We find that all means are negative meaning that all IRSs have decreased over the sample period on average. All series except for 10Y GBP are either significantly left or right skewed. This finding in combination with the event that all series are significantly leptokurtic distributed lead to the result – which is also supported by the Jarque and Bera (1980) normality test – that all series are significantly non-normally distributed at the 1% significance level. More relevant for the employed empirical methodology is the suggestive evidence that all IRSs are stationary (Elliott et al., 1996), autocorrelated and exhibit ARCH/GARCH errors (Fisher and Gallagher, 2012) at least at the 10% significance level. These statistics support our choice of modeling the IRS interdepence using a TVP-VAR with heteroscedastic variance-covariances.

[INSERT TABLE 1 AROUND HERE]

3 Methodology

A widely applied framework to monitor and evaluate spillovers in a predetermined network is the connectedness approach proposed by Diebold and Yılmaz (2009, 2012, 2014). The constantly increasing attention of this particular framework already led to multiple extensions and refinements, such as the asymmetric connectedness approach (Baruník et al., 2017), frequency connectedness approach (Baruník and Křehlík, 2018), wavelet connectedness approach (Antonakakis et al., 2018), Lasso connectedness approach (Demirer et al., 2018), connectedness decomposition approach (Gabauer and Gupta, 2018), factor augmented VAR connectedness approach (Antonakakis et al., 2019a), Elastic-Net and Ridge connectedness approach Gabauer et al. (2020a), DCC-GARCH connectedness approach (Gabauer, 2020), joint spillover approach (Lastrapes and Wiesen, 2021), quantile connectedness approach Chatziantoniou et al. (2021), and global connectedness approach (Greenwood-Nimmo et al., 2021). Among the many, most are focusing on a rolling-window VAR approach that comes with multiple disadvantages such as its outlier sensitivity, the loss of observations, flattened out parameters, and the arbitrarily set window size. Those shortcomings have been tackled by Antonakakis et al. (2020) who have propoed a dynamic connectedness approach based on time-varying parameter vector autoregressions (TVP-VAR) with heteroscedastic variance-covariances which is the main reason why we employ and extend this methodology in the presented paper. One major concern when it comes to the monitoring and interpretation of spillovers is that the using numerous series increases the degree of interpretation complexity. In this paper, we use the aggregated connectedness measures in the spirit of Gabauer and Gupta (2018) and in addition introduce the concept of the conditional connectedness approach. The combination of those two frameworks allow to extract and disentangle spillover pattern supporting the interpretability of the results at hand. This novel concept adds further value to the literature that deals with the introduction, refinement and extension of connectedness measures such as the corrected connectedness index (Chatziantoniou and Gabauer, 2021), pairwise connectedness and (absolute) pairwise influence index (Gabauer, 2021), minimum connectedness portfolio (Broadstock et al., 2020). In our case, the conditional connectedness measures provide information about the currency dynamics disregarding maturity and also about maturity dynamics disregarding currency. With this analysis, it is possible to understand the degree and importance of currency and maturity spillovers, separately.

3.1 Time-varying parameter vector autoregressions

We begin with estimating a TVP-VAR with a lag length of one as suggested by the Bayesian information criterion (BIC) which is mathematically formulated as follows,

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

$$vec(\boldsymbol{B}_t) = vec(\boldsymbol{B}_{t-1}) + \boldsymbol{v}_t \qquad \boldsymbol{v}_t \sim N(\boldsymbol{0}, \boldsymbol{R}_t) \tag{2}$$

where $\boldsymbol{z}_t$, $\boldsymbol{z}_{t-1}$ and $\boldsymbol{u}_t$ are $k \times 1$ dimensional vectors, representing all IRS series in t, $t-1$, and the error term, respectively. $\boldsymbol{B}_t$ and $\boldsymbol{S}_t$ are $k \times k$ dimensional time-varying parameter and variance-covariance matrices whereas $vec(\boldsymbol{B}_t)$ and $\boldsymbol{v}_t$ are $k^2 \times 1$ dimensional vectors and $\boldsymbol{R}_t$ is a $k^2 \times k^2$ dimensional parameter variance-covariance matrix. In a less formular way, it can be said that $\boldsymbol{v}_t$ causes the VAR parameters to vary over time while it is assumed that the variance of $\boldsymbol{v}_t$, namely $\boldsymbol{R}_t$ also changes with time using a Kalman filter approach. Thus, $\boldsymbol{B}_t$ illustrates the time-varying relationship between $\boldsymbol{z}_t$ and their lagged values $\boldsymbol{z}_{t-1}$ whereas the variance-covariances of the error term $\boldsymbol{u}_t$ are of heteroscedastic nature $\boldsymbol{S}_t$.[2] This is highly relevant as the volatility in the financial market varies significantly over time and are of major importance when it comes to risk and portfolio management in general.

[2]The detailed estimation process can be find in the appendix.

3.2 Connectedness approach

Subsequently, we are computing the H-step ahead (scaled) generalized forecast error variance decomposition (GFEVD) in the spirit of Koop et al. (1996) and Pesaran and Shin (1998). The GFEVD is completely invariant of the variable ordering as opposed to the orthogonalized forecast error variance decomposition (see, Diebold and Yılmaz, 2009). It should also be noted that employing structural representations of the respective shocks; that is, a common practice in applied macroeconomics, these shocks should predicate upon some underlying economic theory. As – to the best of our knowledge – no theoretical model concerning IRS spillovers is available, we follow the suggestion of Wiesen et al. (2018) that in the absence of generally accepted theoretical assumptions, the GFEVD analysis should be preferred.[3] Since the GFEVD is based upon vector moving average (VMA) coefficients, we need to transform the TVP-VAR into a TVP-VMA using the Wold representation theorem: $\boldsymbol{z}_t = \sum_{i=1}^{p} \boldsymbol{B}_{it}\boldsymbol{z}_{t-i} + \boldsymbol{u}_t = \sum_{j=0}^{\infty} \boldsymbol{A}_{jt}\boldsymbol{u}_{t-j}$.

The (scaled) GFEVD, $\tilde{\phi}^g_{ij,t}(H)$, normalizes the (unscaled) GFEVD, $\phi^g_{ij,t}(H)$, in order that each row sums up to unity. Thus, $\tilde{\phi}^g_{ij,t}(H)$ represents the influence series j has on series i in terms of its forecast error variance share which can also be defined as the *pairwise directional connectedness from j to i* and 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 zero vector with unity on the ith position.

All connectedness measures invented by Diebold and Yılmaz (2012, 2014) are derived from the GFEVD:

$$C_{i\to\bullet,t} = \sum_{j=1,i\neq j}^{k}\tilde{\phi}^g_{ji,t}(H) \tag{3}$$

$$C_{i\leftarrow\bullet,t} = \sum_{j=1,i\neq j}^{k}\tilde{\phi}^g_{ij,t}(H) \tag{4}$$

$$C_{it} = C_{i\to\bullet,t} - C_{i\leftarrow\bullet,t} \tag{5}$$

$$C_t = \frac{k}{k-1}\sum_{i=1}^{k}C_{i\to\bullet,t} \equiv \frac{k}{k-1}\sum_{i=1}^{k}C_{i\leftarrow\bullet,t}. \tag{6}$$

$C_{i\to\bullet,t}$ represents the aggregated impact a shock in series i has on all other series (defined as the total directional connectedness to others) while $C_{i\leftarrow\bullet,t}$ illustrates the aggregated influence all other series have on series i (defined as the total directional connectedness from others). Subtracting the impact series i has on others by the influence others have on series i results in the net total directional connectedness

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

that identifies whether series i is a net transmitter or a net receiver of shocks. Series i is a net transmitter (receiver) of shocks – and hence driving (driven by) the network – when the impact series i has on others is larger (smaller) than the influence all others have on sreies i, $C_{it} > 0$ ($C_{it} < 0$). Finally, the total connectedness index, C_t, stands for the average shock spillover from one series to all others. A relatively high (low) TCI implies that a shock in one variable on average a high (low) impact on the whole network.

3.3 Aggregated connectedness approach

Subsequently, we follow the decomposition approach of Gabauer and Gupta (2018). Using the aggregated spillovers between six currencies or between three maturities provides an overview of the general propagation mechanism. In this regard, we are interested in how much of the spillovers are transmitted within currencies disregarding their maturitiy or on how much of the spillovers are transmitted between maturities disregarding their currencies. This analysis enables to isolate the effects of currencies and maturities separately. First, we aggregate the GFEVD for d groups – six in terms of currencies or three when it comes to maturities. $C^a_{mn,t} = \sum_{i \in k_m} \sum_{j \in k_n} \tilde{\phi}^g_{ij,t}(H)$ stands for the aggregated impact group n has on group m, where k_m and k_n represent two disjoint index sets. $C^a_{mm,t} = \sum_{i \in k_m} \sum_{j \in k_m} \tilde{\phi}^g_{ij,t}(H)$ is a special case of the previous measure and represents the internal spillovers of group m (all spillovers within the same currency/maturity). In a next step, we compute the group-specific spillovers:

$$C^a_{m \to \bullet,t} = \sum_{n=1, m \neq n}^{d} C^a_{nm,t}$$

$$C^a_{m \leftarrow \bullet,t} = \sum_{n=1, m \neq n}^{d} C^a_{mn,t}$$

$$C^a_{m,t} = C^a_{m \to \bullet,t} - C^a_{m \leftarrow \bullet,t}$$

$$C^a_t = \frac{d}{d-1} \sum_{m=1}^{d} C^a_{m \to \bullet,t} \equiv \frac{d}{d-1} \sum_{m=1}^{d} C^a_{m \leftarrow \bullet,t}$$

where $C^a_{m \to \bullet,t}$ reflects *total group-specific connectedness to others*, $C^a_{m \leftarrow \bullet,t}$ *total group-specific connectedness from others*, $C^a_{m,t}$ *net total group-specific connectedness*, and C^a_t *total group-specific connectedness index*. The aggregated connectedness measures can be interpreted as mentioned previously.

3.4 Conditional connectedness approach

Finally, we would like to introduce the concept of conditional connectedness measures. Those measure are interesting when the transmission mechanism of all currencies given a specific maturity or of all maturities given a certain currency is under investigation.

$$
\begin{aligned}
C_{ij,t|m} =& \frac{C_{ij,t}}{\sum_{j\in k_m} C_{ij,t}} \\
C_{i\to\bullet,t|m} =& \sum_{j\in k_m, j\neq i} C_{ji,t|m} \\
C_{i\leftarrow\bullet,t|m} =& \sum_{j\in k_m, j\neq i} C_{ij,t|m} \\
C_{i,t|m} =& C_{i\to\bullet,t|m} - C_{i\leftarrow\bullet,t|m} \\
C_{t|m} =& \frac{n(k_m)}{n(k_m)-1} \sum_{i=1}^{n(k_m)} C_{i\to\bullet,t|m} \equiv \frac{n(k_m)}{n(k_m)-1} \sum_{i=1}^{n(k_m)} C_{i\leftarrow\bullet,t|m}
\end{aligned}
$$

where $n(k_m)$ stands for the cardinality of set k_m. $C_{i\to\bullet,t|m}$ presents the *conditional total group-specific connectedness to others*, $C_{i\leftarrow\bullet,t|m}$ *conditional total group-specific connectedness from others*, $C_{i,t}$ *conditional net total group-specific connectedness*, and C_t *conditional total group-specific connectedness index*. To put it in another perspective, $C_{i\to\bullet,t|m}$ ($C_{i\leftarrow\bullet,t|m}$) represents by how much currency/maturity i influence (have been influenced by) all other currencies/maturities given a certain maturity/currency. $C_{i\leftarrow\bullet,t|m}$ demonstrates whether currency/maturity i drives (is driven by) the market. Finally, $C_{t|m}$ illustrates the interconnectedness of currencies/maturities given a certain maturity/currency.

4 Empirical results

In this section, we set out the main findings of the study and elaborate on the corresponding implications. The overriding objective is to shed light upon all relevant dimensions of the issue at hand, considering not only spillovers across currencies or across maturities but also, an aggregate dimension, which helps attain a better understanding of the strong linkages that exist within each group of either currencies or maturities. At the same time, we focus on monetary policy implications stressing the critical role of said spillovers on monetary policy decision making. It should also be noted that, the results from a wider network that comprises both different currencies and different maturities has been considered and these findings are included in Appendix A in the interests of completeness (i.e., see Table .1, Figures A.1 and A.2). Nonetheless, in order to reduce the dimensionality and therefore the complication of the analysis, in the main text, we break down the more complicated bigger picture and focus on the three dimensions mentioned above. In this regard, we are able to identify important interrelations within the relevant networks in a more coherent fashion while at the same time we do not miss out any important information.

4.1 Effects by virtue of maturity

We begin by considering spillovers for each currency separately, across different maturities. Findings are given by Table 2.

[INSERT TABLE 2 AROUND HERE]

Starting with total average results, Table 2 reports, for each currency, the average TCI value considering all different maturities. This index shows whether, on average, co-movements – within this network (or system) of different maturities – are either high or low, as it practically records the extent to which the forecast error variance of each maturity can be associated with the innovations in all other maturities in the system. It should also be noted that the main diagonal of individual currencies corresponds to the idiosyncratic (i.e., own-maturity) shocks, whereas off-diagonal elements concern the interaction across different maturities.

Table 2 reports that the TCI values for CHF, DKK, EUR, GBP, NOK, and SEK are 87.12%, 85%, 88.19%, 88.37%, 83.29%, and 86.18%,, respectively. Evidentially, co-movement in this particular network of variables is very strong implying that the underlying setting is very important for understanding dynamics along the maturity spectrum. Furthermore, a closer look at Table 2 reveals that, the main net transmitter of shocks for all currencies is the 5Y IRS. Most importantly, the main net receiver within all relevant networks, without exceptions, is the 2Y IRS. In this regard, total average results indicate that there is indeed contagion along the curve, which mainly translates into longer term rates affecting shorter term rates and whereby, the 5Y rate appears to be the main net transmitter of shocks for all currencies.

Before we discuss potential implications, it would be instructive to extend our analysis by considering a rather more dynamic framework. That is, findings presented in Table 2 merely correspond to total average values for the entire sample period and therefore fail to capture the intertemporal evolution of the interaction across rates. To put differently, a more detailed analysis of the interrelations across the variables of the specific network, would require more than just static results that may mask the impact of economic developments on the network itself. In fact, it would require a dynamic framework which allows the association of spillovers within the system with broader developments in real economic activity. The TVP-VAR connectedness method, presented in the previous section, allows for this level of analysis and therefore facilitates our effort to attain a better understanding of the underlying linkages. To bring everything into perspective, our analysis focuses on two types of results. On the one hand, we have static results which pertain to average values considering the entire sample period as a whole. Static results are typically being reported by Tables which overall provide the average picture of the underlying relations across the entire period of study. On the other hand, we have dynamic results which provide a more granular picture of the issue at hand considering that results no longer refer to average values but rather, correspond to specific points in time. Dynamic results are typically being reported by plots whereby it becomes easier to identify (i) the evolution of the magnitude of connectedness over time, (ii) major events across the sample period that strongly affect the extent of connectedness within the network under investigation, as well as, (iii) shifts in the net position of each one of the variables of the network across periods.

In this regard, we proceed with presenting the net connectedness results for each individual network of currencies. Results are given by Figure 4. Please note that values above (below) zero imply that the specific maturity is a net transmitter (net recipient) of shocks within the system to all other maturities of the same currency.

[INSERT FIGURE 4 AROUND HERE]

What is immediately evident from Figure 4 is that, as far as all currencies are concerned, the 5Y IRS appears to be the dominant net transmitter of shocks throughout the period of analysis. In addition, we cannot identify any time intervals whereby the shorter-term 2Y IRS has had a non-trivial impact as a net transmitter. The longer-term 10Y IRS on the other hand, although it clearly does not have as prominent a role as a net transmitter as the 5Y IRS; it nevertheless, assumes a net transmitting role for very short periods considering mainly CHF, DKK, NOK, and SEK. However, even when we take these intervals into account, we cannot really argue that the 10Y IRS is either a dominant or a persistent net transmitter within these networks. Overall, net connectedness findings suggest that both the shorter-term 2Y IRS and the longer-term 10Y IRS receive feedback from the 5Y IRS which is the dominant net transmitter and thus largely determines innovations within the specific systems.

[INSERT FIGURE 3 AROUND HERE]

4.2 Effects by virtue of currency

We then turn to spillovers for each maturity separately, across different currencies. Findings are given by Table 3.

[INSERT TABLE 3 AROUND HERE]

In line with the previous section, we start with an exposition of total average results. Table 3 reports, for each maturity, the average TCI value considering all different currencies. Apparently, the TCI values for the 2Y, 5Y, and 10Y IRS across the different currencies are are 64.48%, 78.89%, and 82.11%, respectively. These findings provide strong indication that within each separate maturity network, interaction and co-movement among currencies is rather strong. To put differently, within each maturity group, developments in the IRS of each currency are closely associated with innovations in the IRS of all other currencies. The observation that the TCI values are higher for the medium- and long-term swaps is consistent with the earlier findings from the bond market – noting that the long-term bond market is more integrated than the short-term (Jotikasthira et al., 2015; Kumar and Okimoto, 2011).

It is also worth pointing out that the dominant transmitter for all three different IRS maturities is the EUR, followed by the DKK. The transmitting role of EUR is expected, given that it is the most widely traded interest rate derivatives market in the world after the USD. Indeed, EUR make up more than two-thirds of the IRS-turnover in European currencies. The dominant role of the Danish krona might seem surprising, given that it is the least traded currency within the group of six. However, the observation echoes the findings by Chatziantoniou et al. (2020) on the cross-currency basis swap market. Because the DKK is pegged to EUR, it automatically obtains a similar role to EUR – regardless of whether it acts as a transmitter or receiver of shocks. By contrast, all other rates, considering all three different maturities appear to be net recipients of shocks in their respective networks.On the whole, findings suggest that it is mainly the Euro IRS which drives developments in the rates of other currencies (i.e., irrespective of maturity).

We then turn to Figure 6 which illustrates total net connectedness results and highlights the dynamic character of our framework.

[INSERT FIGURE 6 AROUND HERE]

Figure 6 echoes the average results presented above. It is evident that EUR IRSs are the main and the most persistent transmitters of shocks into their respective networks throughout the period of analysis. The same goes for DKK, although the currency also has acted as a receiver of shocks during two episodes, namely around the turn of the millennium (which signified substantial volatility in short-term interest rates) and the GCF. With regards to the CHF IRS, we note that the Swiss franc has become a net transmitter of shocks only recently (since January 2015). This shift coincides with the sudden and highly unexpected decision by the Swiss National Bank to abandon the EUR-peg after a period of three years. This prompted a surge in the Swiss franc and a dramatic fall in short-term interest rate swap prices (see Figure 1).

GBP IRSs have typically been receivers of shocks. However, there are also three notable exceptions when the British pound has transmitted shocks to other currencies. This includes a long period between 2002 and 2006 when GBP swap rates were either higher than or diverging from other European rates. The GFC and the Brexit referendum in 2016 also triggered GBP IRSs to transmit shocks to the system temporarily. Since then, however, the role of GBP as a receiver has increased.

SEK assumes a net receiving role across time, exhibiting only very short periods of rather a moderate transmission activity. One such episode is the first quarter of 2015. The Swedish Riksbank pioneered with negative interest rates in 2009. However, this referred to deposit rates for commercial bank holding with the central bank. The repo rate (which is more influential on SEK IRS prices) was cut to -0.10% in February 2015 and to -0.50% in 2016. Since March 2020, when the COVID-19 outbreak started to have a significant impact on global financial markets, SEK has consistently been a transmitter of shocks to the network. Finally, NOK stands out by being the most consistent receiver of shocks.

[INSERT FIGURE 5 AROUND HERE]

4.3 Aggregate dimensions

Finally, in order to further highlight the importance of both linkages across currencies and linkages across maturities, we present aggregate connectedness results; that is, we include another two auxiliary networks, whereby, we focus on either the aggregate currency dimension or the aggregate maturity dimension, but not on both dimensions simultaneously.

Starting with the aggregate currency dimension, findings are given by Table 4.

[INSERT TABLE 4 AROUND HERE]

As far as average results are concerned, co-movement within this particular network is very strong given that the value of the TCI is equal to 79.56% implying that the extent to which the forecast error of the IRS of each currency is highly associated with the innovations in all other currencies in the system (i.e., considering all maturities in tandem). In line with previous findings we note that, on average, it is again the EUR IRS and the DKK IRS that have a dominant net transmitting role.

With regard to dynamic results, we set out two relevant figures. The first, is Figure 7 which illustrates the evolution of the TCI index across time.

[INSERT FIGURE 7 AROUND HERE]

Evidently, connectedness across the variables of this specific network is very strong throughout most of our sample period, given that the TCI assumes values greater than 80% on a number of occasions.

The measure peaks and reaches a value close to 90% during the crisis in 2008, and significant drops are only shown in the immediate aftermath of European monetary policy divergence (2001 and early 2015). Thus, although the connectedness appears to be event dependent as there is a fluctuation of the value of TCI over time, periods of decoupling of rates across different currencies tend to be few and relatively short-lived.

In turn, Figure 8, in line with the previous analysis, presents the net dynamic spillovers. In line with the previous findings, we note that, on average, it is again the EUR and the DKK that have a dominant net transmitting role – although the role of Danish krone appears to have weakened somewhat in recent years. In 2015, CHF switched from being a receiver to a transmitter of shocks. GBP and SEK have been receivers, with the exception of a few previously documented episodes. NOK, finally, has been a persistent receiver of shocks from the network.

[INSERT FIGURE 8 AROUND HERE]

We then turn to the aggregate maturity dimension. Findings are given by Table 5.

[INSERT TABLE 5 AROUND HERE]

We begin by presenting average results, whereby co-movement within the system is again considerably strong considering that the average value of the TCI across the entire sample period is equal to 91.95%

(i.e., considering all currencies in tandem). In line with previous findings, longer term IRS are net transmitters while, on average, the 2Y IRS is again a net recipient of spillover shocks.

With reference to the evolution of TCI over time, results are illustrated in Figure 9.

[INSERT FIGURE 9 AROUND HERE]

Notably, for almost the entire sample period of our study, the TCI assumes values within the range of 85% to 95%. As mentioned earlier, this dynamic exposition of connectedness results further allows us to ascertain the close link of the index to developments in real economic life - as evidenced by the fluctuation of the TCI value over time. A closer look indicates that connectedness assumes relatively smaller values again in 2001 and 2015. The pattern of the aggregate maturity dimension is similar to that of the aggregate currency dimension (see Figure 9). The results can also be read in the context of the preferred-habitat theory of term structure of interest rates, which proposes a strong degree of segmentation in markets depending on time to maturity (Modigliani and Sutch, 1966). Several historical episodes, such as the US Treasury buyback program of 2000-2002 and the UK pension reform in 2004, suggest that certain bond maturities can decouple and behave more independently for a while (Greenwood and Vayanos, 2010). Nonetheless, the TCI values are consistently higher, and the two notable drops shorter and less pronounced when studying connectedness along the yield curves. This suggests that periods of decoupling of IRSs across different European currencies are associated with weaker connectedness along the yield curves.

Finally, we turn our attention to Figure 10 which illustrates the net dynamic connectedness results for this network of variables.

[INSERT FIGURE 10 AROUND HERE]

What is clear from Figure 10 is that the 5Y IRS is the most persistent net transmitter of shocks into the system. The 2Y IRS has been a persistent net recipient of shocks since 1999. Notably, the role of the 2Y as a receiver has increased substantially since around mid-2012. This is also the point in time when the 10Y IRS evolved from having had a mixed role to becoming a substantial transmitter of shocks – and even surpassing the 5Y IRS in this respect. The marked shift in the pattern coincides with the ECB Governor Draghi's famous 'whatever it takes' speech on 26 July 2012 (ECB, 2012). The speech, which essentially included a commitment to reduce risk premia on Eurozone government bonds to "save the euro", resulted in significant and lasting suppression of EUR-denominated yields – including for IRSs.

5 Conclusions and Policy Implications

In this paper, we investigate the time-varying transmission mechanism between 2Y, 5Y and 10Y IRSs for six European currencies (CHF, DKK, EUR, GBP, NOK and SEK) from 1999 to 2021. The cross-maturity/cross-currency matrix framework of analysis combines the TVP-VAR algorithm developed by

Koop and Korobilis (2014) with the dynamic connectedness approach introduced by Diebold and Yilmaz (2012, 2014). We should emphasize that, the present study focuses on yield interaction across currencies and maturities in order to improve our understanding regarding (i) the evolution of said relations over time and (ii) the potential for contagion across these variables and the corresponding implications for monetary policy. In this regard, a dynamic connectedness approach is a rather suitable method to address the issue at hand. The time-varying version of connectedness employed in this study, has a number of merits regarding the more accurate estimation of parameters, including (i) the exclusion of outliers that typically affect results and (ii) the inclusion of all observations in the estimation of the parameters considering that the estimation is not based on an arbitrarily chosen rolling window.

Our key findings can be summarised as follows. First, when seen from a maturity dimension for the period of study as a whole, co-movement is extremely strong within these networks (ranging from 83.29% for NOK to over 88% for EUR and GBP). The 5Y IRS is the main transmitter in the CHF, DKK, EUR and SEK markets, and the 10Y IRS in the GBP and NOK markets. The 2Y IRS is a net receiver within all networks. However, a more nuanced picture emerges when studying the evolution of the transmission mechanism over time. Seen from this perspective, the 2Y IRS role as a net receives of shocks has gradually increased over time. The 10Y IRS, by contrast, has increasingly assumed a net-transmitting position in the CHF, DKK, NOK and SEK markets.

Second, when approaching the same networks from a currency dimension, strong co-movement is also documented. The TCI values for the 2Y, 5Y and 10Y IRS across the different currencies are 64.48%, 78.89% and 82.11%, respectively. Thus, within each benchmark maturity, developments in the IRS of each currency are closely associated with innovations in the IRS of all other currencies. The higher TCI values for the medium- and long-term swaps are in line with findings from the bond market, which demonstrate more integration in the long-term, rather than the short-term, bond market (Jotikasthira et al., 2015; Kumar and Okimoto, 2011). EUR is the most prominent transmitter of shocks within this network, followed by the closely-pegged DKK – echoing the findings by Chatziantoniou et al. (2020) on the cross-currency basis swap market. Notably, CHF switched from being a net receiver to a net transmitter after the decision by the Swiss National Bank to abandon the EUR-peg in January 2015. GBP IRSs have mainly been receivers of shocks, except for during 2002-2006, the GCF and the Brexit referendum in 2016. Since then, however, the role of GBP as a receiver has increased. SEK has normally assumed a net receiving role across time, and NOK stands out by being the most consistent receiver of shocks.

Third, when studying the aggregated currency dynamic total connectedness, we note that the TCI values often exceed 80% and peaks around 90% during the GCF. The TCI values for the aggregated maturity dynamic total connectedness are even higher and more consistent. Only two significant drops are reported – both in the immediate aftermath of European monetary policy divergence in 2001 and early 2015. Put together; the results suggest that periods of decoupling of IRSs across different European currencies are also associated with weaker connectedness along the yield curves. From a combined cross-currency and cross-maturity perspective, we document that the 5Y IRS is the most persistent net transmitter of shocks into the system. The 2Y IRS has been a persistent net recipient of shocks since 1999. However, the role of the 2Y as a receiver has increased substantially since around mid-2012. This coincides with a in time when the 10Y IRS evolved from having had a mixed role to even surpassing the 5Y IRS as a net transmitter of shocks.

The findings have important implications for policymaking. Whereas European interest rate markets have been extremely connected for a long period of time, a more nuanced analysis shows that the transmission mechanism of shocks has evolved considerably in recent years. The euro continues to be the primary transmitter of shocks, but the originating source has shifted further along the yield curve towards the 10-year segment. At the same time, the receiving role of more minor currencies (most notably SEK and NOK) have shifted to shorter maturities. This suggests that the ECB has strengthened its ability to influence monetary conditions beyond the Eurozone. It also implies that central banks such as Sveriges Riksbank and Norges Bank have been increasingly dependent on the development in longer-term maturities home and abroad. Put together; this means that role of the domestic short-term interest rate has lost relevance for the monetary transmission mechanism at the expense of the foreign long-term interest rate.

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Table 1: Summary Statistics

	2YCHF	5YCHF	10YCHF	2YDKK	5YDKK	10YDKK	2YEUR	5YEUR	10YEUR	2YGBP	5YGBP	10YGBP	2YNOK	5YNOK	10YNOK	2YSEK	5YSEK	10YSEK
Mean	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Variance	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
Skewness	-0.19***	-0.16***	0.07**	0.50***	0.32***	0.14***	0.21***	0.29***	0.24***	0.19***	0.08**	0.01	-0.80***	-0.21***	1.71***	-0.28***	0.14***	0.17***
	(0.00)	(0.00)	(0.04)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.76)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Excess	14.19***	6.11***	2.55***	8.34***	3.05***	2.48***	6.96***	2.88***	2.69***	5.73***	2.95***	1.72***	12.04***	6.47***	51.01***	6.76***	3.54***	2.93***
Kurtosis	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
JB	46651***	8663***	1505***	16324***	2248***	1439***	11275.55***	1999***	1729***	7641***	2017***	687***	34176.53***	9746***	605322***	10659***	2920***	2012.24***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
ERS	-7.70***	-9.16***	-16.87***	-5.03***	-4.83***	-4.15***	-11.46***	-20.12***	-20.14***	-8.21***	-10.67***	-9.88***	-6.12***	-10.78***	-6.10***	-4.33***	-4.54***	-4.86***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$Q(20)$	142.44***	85.87***	39.19***	48.46***	39.39***	29.83*	65.14***	37.42***	27.43 *	77.96***	29.57*	31.62**	91.17***	81.56***	40.97***	106.23***	52.81***	40.43***
	(0.00)	(0.00)	(0.01)	(0.00)	(0.01)	(0.07)	(0.00)	(0.01)	(0.12)	(0.00)	(0.08)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$Q^2(20)$	421.99***	541.50***	720.81***	1034.28***	889.18***	849.48***	1326.39***	1135.31***	1175.21***	1221.14***	535.97***	443.86***	1319.68***	1748.63***	113.72***	812.88***	824.08***	727.41***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

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

Table 2: Conditional currency-specific connectedness table

	2YCHF	5YCHF	10YCHF	FROM
2YCHF	44.50	32.17	23.33	55.50
5YCHF	28.52	38.92	32.56	61.08
10YCHF	22.30	35.36	42.34	57.66
TO	50.82	67.53	55.88	TCI
NET	-4.68	6.46	-1.78	87.12
NPDC	0.00	2.00	1.00	

	2YDKK	5YDKK	10YDKK	FROM
2YDKK	46.44	30.29	23.27	53.56
5YDKK	26.83	40.40	32.77	59.60
10YDKK	21.86	34.98	43.17	56.83
TO	48.69	65.27	56.04	TCI
NET	-4.87	5.67	-0.79	85.00
NPDC	0.00	2.00	1.00	

	2YEUR	5YEUR	10YEUR	FROM
2YEUR	43.79	32.81	23.40	56.21
5YEUR	28.90	38.18	32.92	61.82
10YEUR	22.44	35.91	41.65	58.35
TO	51.34	68.72	56.32	TCI
NET	-4.86	6.89	-2.03	88.19
NPDC	0.00	2.00	1.00	

	2YGBP	5YGBP	10YGBP	FROM
2YGBP	43.35	32.92	23.74	56.65
5YGBP	29.33	38.25	32.43	61.75
10YGBP	22.99	35.33	41.67	58.33
TO	52.32	68.25	56.17	TCI
NET	-4.34	6.50	-2.16	88.37
NPDC	0.00	2.00	1.00	

	2YNOK	5YNOK	10YNOK	FROM
2YNOK	45.77	32.26	21.97	54.23
5YNOK	29.06	41.25	29.69	58.75
10YNOK	21.34	32.26	46.39	53.61
TO	50.40	64.52	51.65	TCI
NET	-3.83	5.78	-1.95	83.29
NPDC	0.00	2.00	1.00	

	2YSEK	5YSEK	10YSEK	FROM
2YSEK	45.06	31.17	23.77	54.94
5YSEK	27.50	39.96	32.54	60.04
10YSEK	22.49	34.89	42.62	57.38
TO	50.00	66.05	56.31	TCI
NET	-4.94	6.01	-1.07	86.18
NPDC	0.00	2.00	1.00	

Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Table 3: Conditional maturity-specific connectedness table

	2YCHF	2YDKK	2YEUR	2YGBP	2YNOK	2YSEK	FROM
2YCHF	44.77	13.96	16.29	10.29	5.42	9.27	55.23
2YDKK	12.28	39.82	24.96	8.90	4.74	9.31	60.18
2YEUR	13.34	23.40	37.29	10.94	5.10	9.93	62.71
2YGBP	11.23	11.21	14.36	49.71	4.98	8.50	50.29
2YNOK	7.35	7.66	8.70	6.20	59.19	10.89	40.81
2YSEK	10.48	11.88	13.34	8.52	8.96	46.83	53.17
TO	54.68	68.11	77.65	44.84	29.20	47.90	TCI
NET	-0.55	7.93	14.94	-5.45	-11.60	-5.27	64.48
NPDC	3.00	4.00	5.00	2.00	0.00	1.00	

	5YCHF	5YDKK	5YEUR	5YGBP	5YNOK	5YSEK	FROM
5YCHF	34.80	15.96	16.98	11.74	8.33	12.19	65.20
5YDKK	13.69	29.24	23.74	12.31	8.09	12.94	70.76
5YEUR	14.10	23.02	28.65	13.41	7.97	12.86	71.35
5YGBP	12.35	15.02	16.90	36.35	7.76	11.62	63.65
5YNOK	10.33	11.94	12.32	9.27	42.74	13.40	57.26
5YSEK	12.42	15.49	15.99	11.26	11.09	33.76	66.24
TO others	62.89	81.42	85.93	57.98	43.23	63.00	TCI
NET	-2.31	10.66	14.58	-5.67	-14.03	-3.24	78.89
NPDC	3.00	4.00	5.00	1.00	0.00	2.00	

	10YCHF	10YDKK	10YEUR	10YGBP	10YNOK	10YSEK	FROM
10YCHF	33.84	15.60	16.55	12.61	9.07	12.33	66.16
10YDKK	13.06	27.64	22.76	14.19	9.24	13.12	72.36
10YEUR	13.46	22.02	27.02	15.58	9.10	12.82	72.98
10YGBP	12.25	16.51	18.68	32.58	8.32	11.66	67.42
10YNOK	10.72	13.56	13.80	10.36	36.92	14.64	63.08
10YSEK	12.33	15.80	16.02	12.05	12.34	31.48	68.52
TO	61.82	83.49	87.80	64.78	48.07	64.58	TCI
NET	-4.34	11.13	14.82	-2.64	-15.01	-3.95	82.11
NPDC	1.00	4.00	5.00	3.00	0.00	2.00	

Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Table 4: Currency connectedness table

	CHF	DKK	EUR	GBP	NOK	SEK	FROM
CHF	33.99	15.91	17.39	12.42	8.19	12.10	66.01
DKK	13.97	29.11	23.46	12.76	8.06	12.64	70.89
EUR	14.45	22.22	28.61	14.07	8.08	12.56	71.39
GBP	12.75	15.11	17.42	35.75	7.55	11.42	64.25
NOK	10.43	11.99	12.68	9.41	41.36	14.15	58.64
SEK	12.61	15.08	15.83	11.50	11.61	33.38	66.62
TO	64.19	80.31	86.76	60.16	43.50	62.87	TCI
NET	-1.82	9.42	15.37	-4.09	-15.14	-3.75	79.56
NPDC	3.00	4.00	5.00	2.00	0.00	1.00	

Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Table 5: Maturity connectedness table

	2Y	5Y	10Y	FROM
2Y	36.96	34.42	28.62	63.04
5Y	27.04	37.83	35.13	62.17
10Y	22.92	35.76	41.32	58.68
TO	49.97	70.18	63.75	TCI
NET	-13.07	8.01	5.06	91.95
NPDC	0.00	2.00	1.00	

Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure 1: Interest Rate Swaps

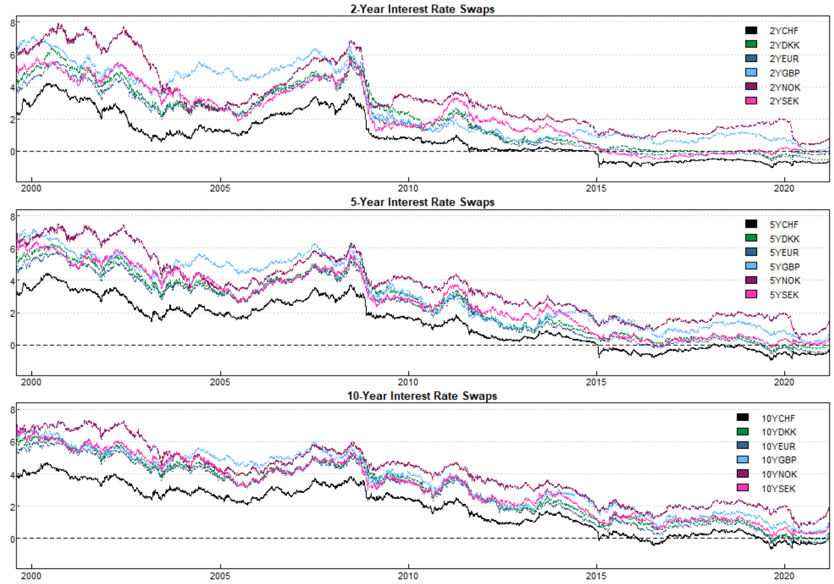


Figure 2: Interest Rate Swap Returns

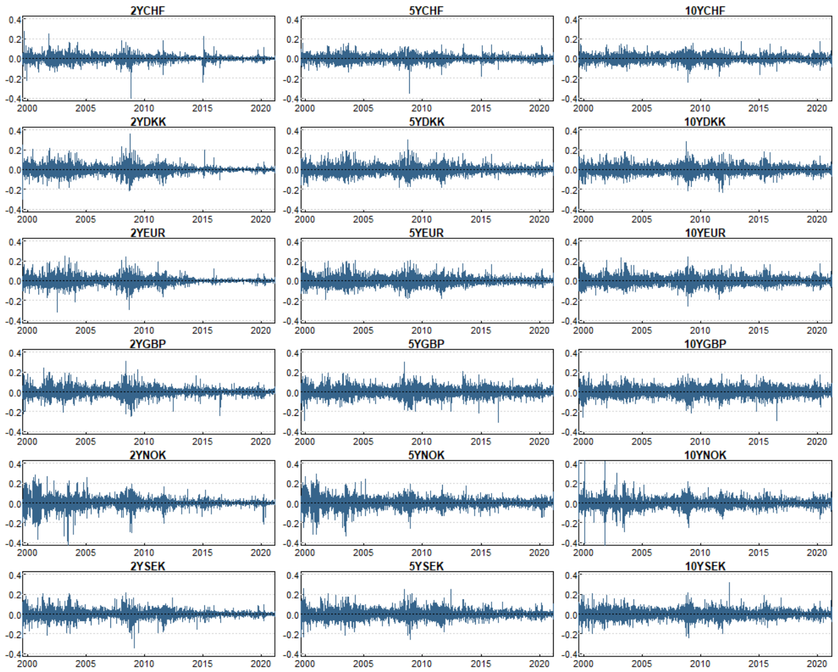
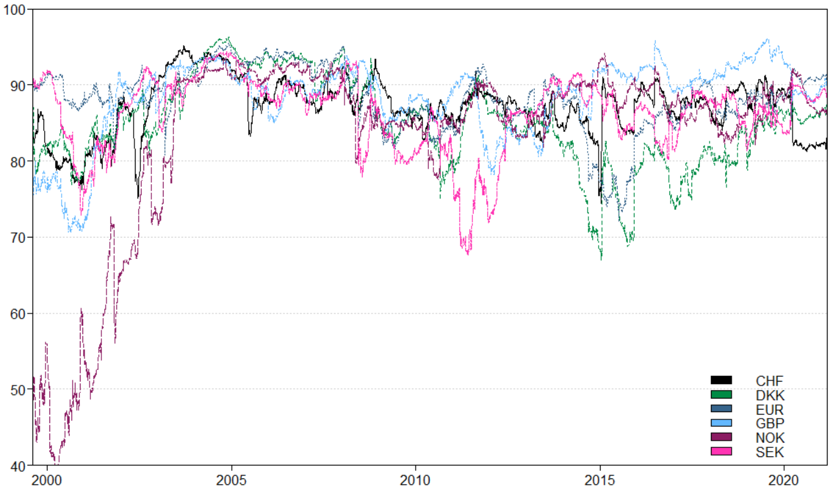
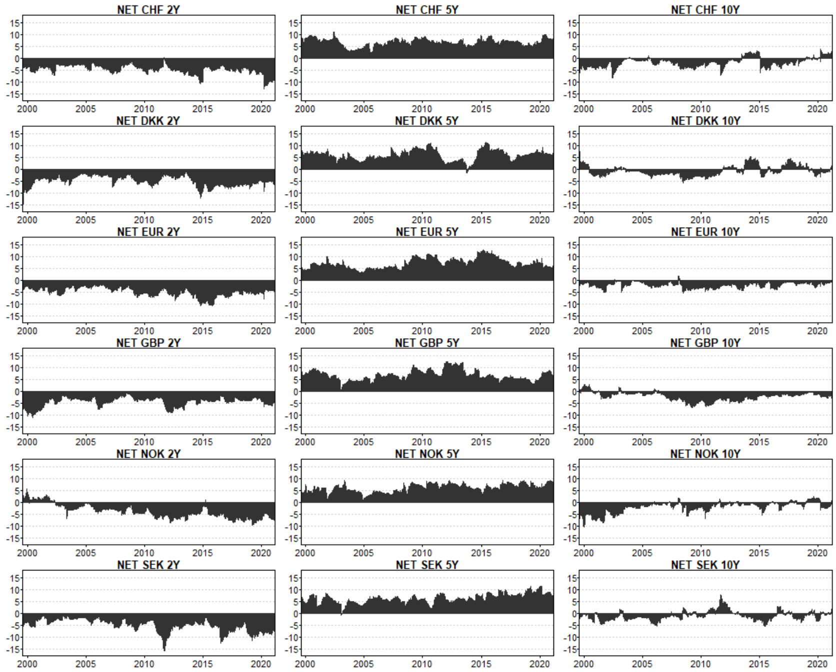


Figure 3: Conditional currency dynamic total connectedness



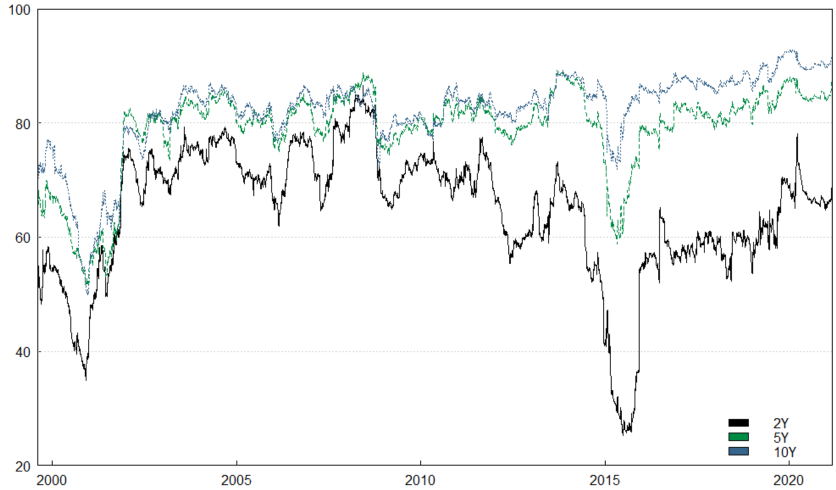
Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure 4: Conditional currency net total directional connectedness



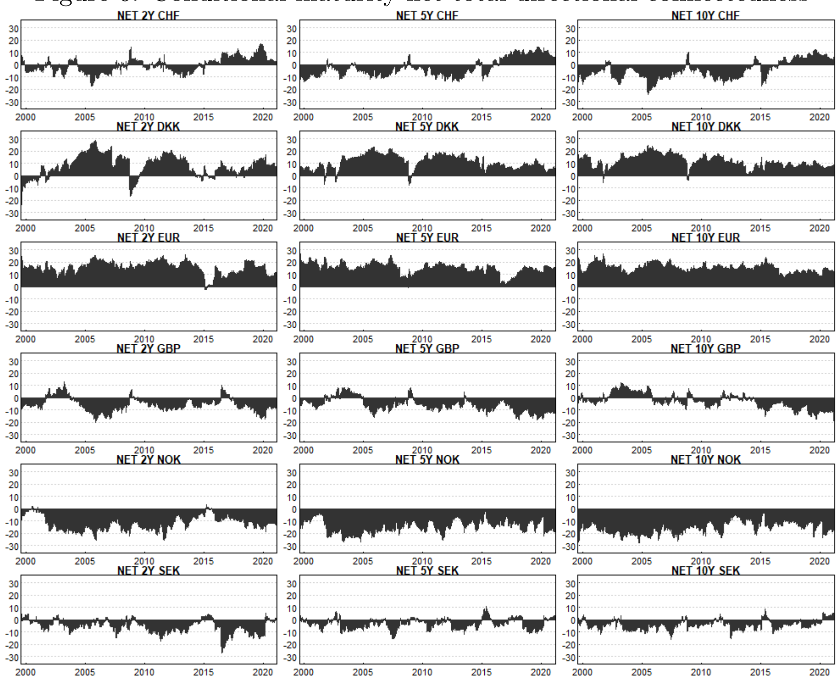
Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure 5: Conditional maturity dynamic total connectedness



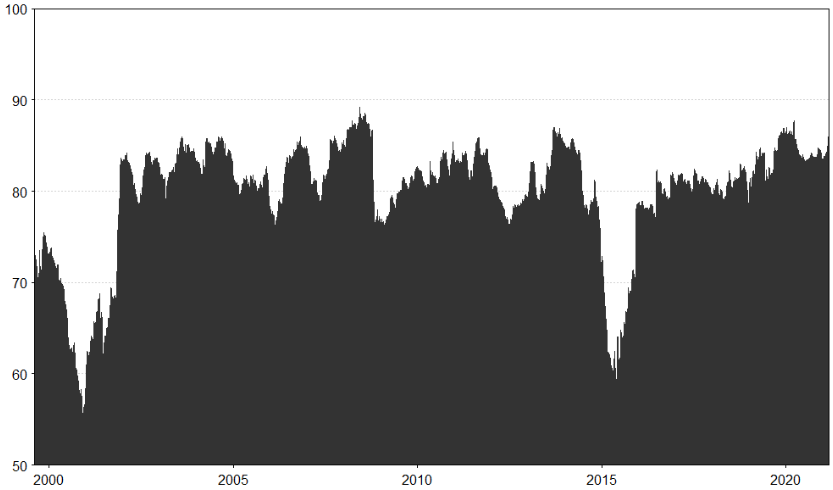
Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure 6: Conditional maturity net total directional connectedness



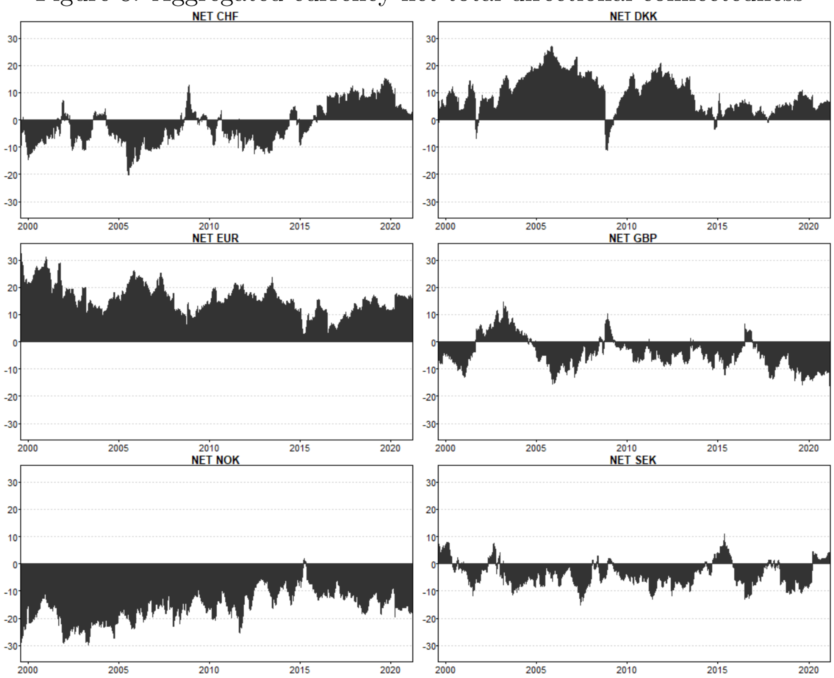
Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure 7: Aggregated currency dynamic total connectedness



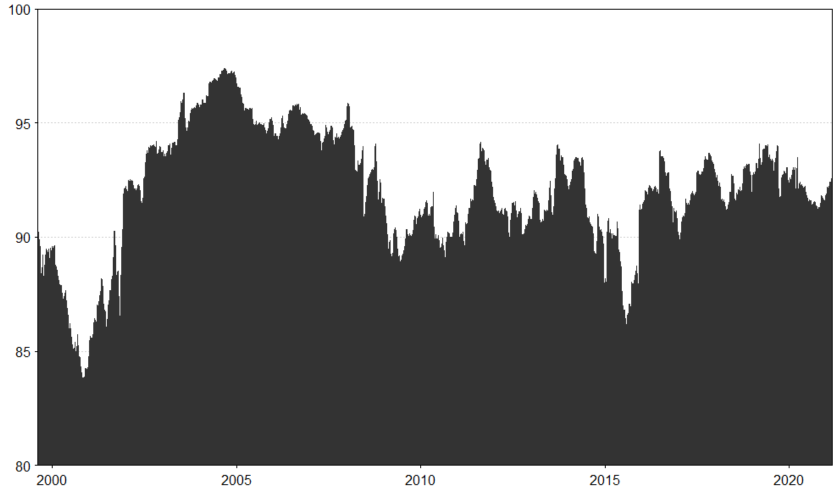
Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure 8: Aggregated currency net total directional connectedness



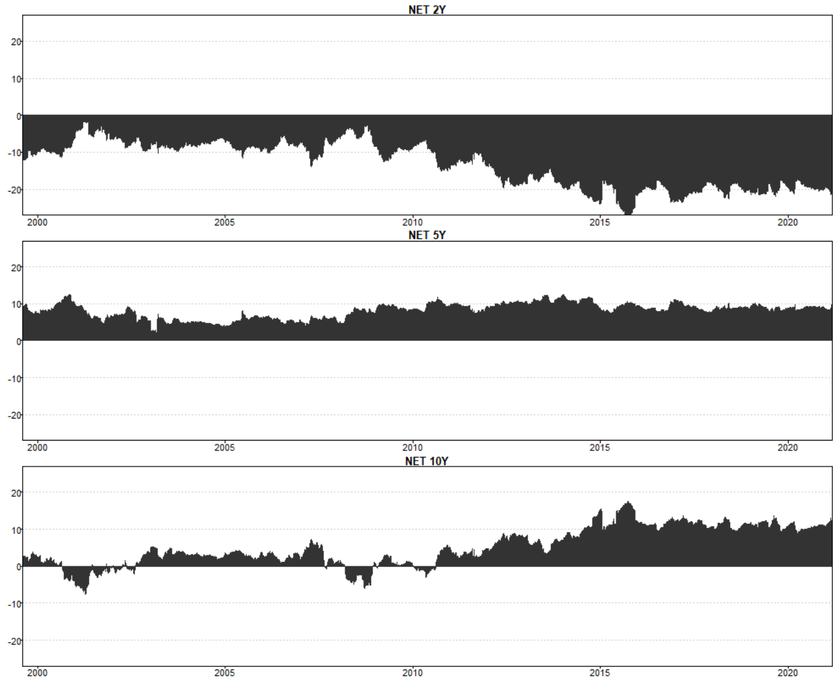
Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure 9: Aggregated maturity dynamic total connectedness



Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure 10: Aggregated maturity net total directional connectedness



Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Appendix

.1 Technical Appendix

The TVP-VAR is represented as follows,

$$\begin{aligned} \boldsymbol{z}_t =& \boldsymbol{B}_t \boldsymbol{z}_{t-1} + \boldsymbol{u}_t & \boldsymbol{u}_t \sim N(\boldsymbol{0}, \boldsymbol{S}_t) \\ vec(\boldsymbol{B}_t) =& vec(\boldsymbol{B}_{t-1}) + \boldsymbol{v}_t & \boldsymbol{v}_t \sim N(\boldsymbol{0}, \boldsymbol{R}_t) \end{aligned}$$

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

An empirical Bayes prior is applied where the priors, $vec(\boldsymbol{B}_0)$ and $\boldsymbol{S}_0$, are equal to the estimation results of a constant parameter VAR estimation based on the first 200-days.

$$\begin{aligned} vec(\boldsymbol{B}_0) \sim& N(vec(\boldsymbol{B}_{OLS}), \boldsymbol{R_{OLS}}) \\ \boldsymbol{S}_0 =& \boldsymbol{S}_{OLS}. \end{aligned}$$

The Kalman Filter estimation relies on forgetting factors ($0 \leq \kappa_i \leq 1$) which regulates how fast the estimated coefficients vary over time. If the forgetting factor is set equal to 1 the algorithm collapses to a constant parameter VAR. Since it is assumed that parameters are not changing dramatically from one day to anothe, κ_2 is set equal to 0.99:

$$\begin{aligned} vec(\boldsymbol{B}_t)|\boldsymbol{Z}_{1:t-1} \sim& N(vec(\boldsymbol{B}_{t|t-1}), \boldsymbol{R}_{t|t-1}) \\ vec(\boldsymbol{B}_{t|t-1}) =& vec(\boldsymbol{B}_{t-1|t-1}) \\ \boldsymbol{R}_t =& (1 - \kappa_2^{-1}) \boldsymbol{R}_{t-1|t-1} \\ \boldsymbol{R}_{t|t-1} =& \boldsymbol{R}_{t-1|t-1} + \boldsymbol{R}_t \end{aligned}$$

The multivariate EWMA procedure for $\boldsymbol{\Sigma}_t$ is updated in every step, while κ_1 and κ_2 are set equal to 0.99 based on the sensitivity results provided by Koop and Korobilis (2014). Furthermore, Koop and Korobilis (2014) fix the forgetting factors, as well, even if the forgetting factors can be estimated by the data, as in Koop and Korobilis (2013). The main reason to fix the parameters is twofold (i) it increases computational burden substantially and (ii) the value added to the forecasting performance it questionable.

$$\begin{aligned} \hat{\boldsymbol{u}}_t =& \boldsymbol{z}_t - \boldsymbol{B}_{t|t-1} \boldsymbol{z}_{t-1} \\ \boldsymbol{S}_t =& \kappa_1 \boldsymbol{S}_{t-1|t-1} + (1 - \kappa_1) \hat{\boldsymbol{u}}_t' \hat{\boldsymbol{u}}_t \end{aligned}$$

$vec(\boldsymbol{B}_t)$ and $\boldsymbol{R}_t$ are updated by

$$
\begin{aligned}
vec(\boldsymbol{B}_t)|\boldsymbol{z}_{1:t} \sim & N(vec(\boldsymbol{B}_{t|t}), \boldsymbol{R}_{t|t}) \\
vec(\boldsymbol{B}_{t|t}) = & vec(\boldsymbol{B}_{t|t-1}) + \boldsymbol{R}_{t|t-1}\boldsymbol{z}'_{t-1}(\boldsymbol{S}_t + \boldsymbol{z}_{t-1}\boldsymbol{R}_{t|t-1}\boldsymbol{z}'_{t-1})^{-1}(\boldsymbol{z}_t - \boldsymbol{B}_{t|t-1}\boldsymbol{z}_{t-1}) \\
\boldsymbol{R}_{t|t} = & \boldsymbol{R}_{t|t-1} + \boldsymbol{R}_{t|t-1}\boldsymbol{z}'_{t-1}(\boldsymbol{S}_t + \boldsymbol{z}_{t-1}\boldsymbol{R}_{t|t-1}\boldsymbol{z}'_{t-1})^{-1}(\boldsymbol{z}_{t-1}\boldsymbol{R}_{t|t-1})
\end{aligned}
$$

Finally, the variances, $\boldsymbol{S}_t$, are updated by the EWMA procedure

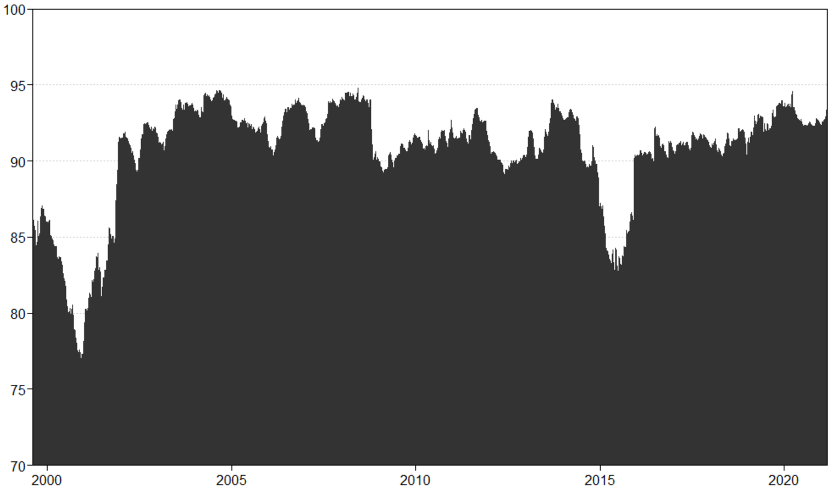
$$
\begin{aligned}
\hat{\boldsymbol{u}}_{t|t} = & \boldsymbol{z}_t - \boldsymbol{B}_{t|t}\boldsymbol{z}_{t-1} \\
\boldsymbol{S}_{t|t} = & \kappa_1 \boldsymbol{S}_{t-1|t-1} + (1-\kappa_1)\hat{\boldsymbol{u}}'_{t|t}\hat{\boldsymbol{u}}_{t|t}
\end{aligned}
$$

Table .1: Averaged connectedness table

	2YCHF	5YCHF	10YCHF	2YDKK	5YDKK	10YDKK	2YEUR	5YEUR	10YEUR	2YGBP	5YGBP	10YGBP	2YNOK	5YNOK	10YNOK	2YSEK	5YSEK	10YSEK	FROM
2YCHF	16.2	11.6	8.3	5.0	5.8	4.9	5.9	6.0	5.1	3.7	4.3	4.2	1.9	2.7	2.8	3.4	4.3	3.9	83.8
5YCHF	9.6	13.1	10.8	4.2	6.0	5.6	5.1	6.4	6.0	3.3	4.4	4.6	1.9	3.1	3.4	3.1	4.6	4.6	86.9
10YCHF	7.2	11.3	13.8	3.8	6.0	6.3	4.5	6.4	6.7	3.1	4.5	5.1	1.8	3.2	3.7	2.8	4.6	5.0	86.2
2YDKK	4.7	4.7	4.1	15.8	10.0	7.5	9.6	7.9	5.8	3.4	3.9	3.8	1.8	2.6	2.8	3.5	4.4	3.7	84.2
5YDKK	4.1	5.2	5.1	7.4	11.1	9.0	7.0	9.0	7.9	3.4	4.6	5.0	1.7	3.1	3.5	3.3	4.9	4.8	88.9
10YDKK	3.6	5.0	5.5	5.8	9.3	11.5	5.3	8.4	9.5	3.3	5.0	5.9	1.7	3.1	3.9	2.9	4.9	5.4	88.5
2YEUR	4.8	5.2	4.5	8.5	8.3	6.1	13.6	10.0	7.1	4.0	4.4	4.3	1.9	2.7	2.9	3.6	4.5	3.9	86.4
5YEUR	4.1	5.3	5.1	5.8	8.6	7.8	8.1	10.8	9.3	3.6	5.0	5.5	1.7	3.0	3.4	3.2	4.8	4.8	89.2
10YEUR	3.6	5.2	5.6	4.5	8.0	9.2	6.1	9.7	11.3	3.5	5.4	6.5	1.7	3.2	3.8	2.8	4.7	5.3	88.7
2YGBP	3.9	4.4	3.9	4.0	5.1	4.8	5.1	5.7	5.2	17.4	13.1	9.4	1.7	2.6	2.7	3.0	4.1	3.8	82.6
5YGBP	3.7	4.6	4.5	3.7	5.6	5.9	4.6	6.3	6.6	10.3	13.6	11.5	1.6	2.9	3.2	2.8	4.3	4.4	86.4
10YGBP	3.5	4.7	5.0	3.6	5.9	6.7	4.4	6.7	7.6	7.3	11.4	13.4	1.6	2.9	3.4	2.7	4.3	4.8	86.6
2YNOK	2.8	3.3	3.1	2.9	3.5	3.2	3.3	3.7	3.4	2.3	2.7	2.6	23.5	16.3	10.4	4.1	4.6	4.4	76.5
5YNOK	2.8	3.9	3.9	3.1	4.5	4.6	3.5	4.7	4.7	2.6	3.5	3.7	11.9	17.2	11.2	3.7	5.1	5.3	82.8
10YNOK	2.9	4.2	4.5	3.3	5.2	5.6	3.7	5.3	5.7	2.6	3.9	4.3	7.1	10.7	15.8	3.7	5.5	6.1	84.2
2YSEK	3.9	4.2	3.7	4.4	5.1	4.4	4.9	5.3	4.4	3.1	3.7	3.6	3.3	4.0	3.9	17.2	11.9	9.0	82.8
5YSEK	3.6	4.7	4.6	4.1	5.8	5.6	4.6	6.0	5.7	3.2	4.2	4.3	2.8	4.2	4.5	8.8	12.8	10.3	87.2
10YSEK	3.3	4.8	5.1	3.5	5.8	6.4	4.0	6.0	6.6	3.0	4.4	4.9	2.6	4.4	5.1	6.8	10.4	12.9	87.1
TO	72.0	92.3	87.3	77.6	108.6	103.7	89.7	113.4	107.3	65.7	88.5	89.1	48.8	74.7	74.6	64.1	92.0	89.8	TCI
NET	-11.8	5.4	1.0	-6.6	19.7	15.2	3.3	24.2	18.6	-16.9	2.0	2.6	-27.7	-8.0	-9.7	-18.7	4.8	2.7	90.5
NPDC	5.0	13.0	9.0	6.0	16.0	14.0	12.0	17.0	15.0	2.0	7.0	11.0	0.0	3.0	4.0	1.0	10.0	8.0	

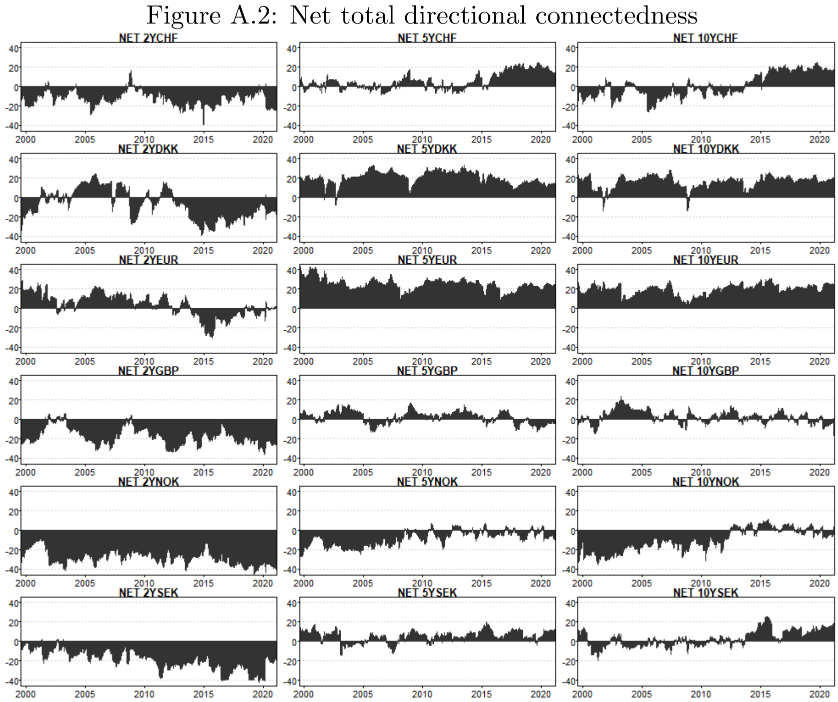
Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure A.1: Dynamic total connectedness



Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.

Figure A.2: Net total directional connectedness



Notes: Results are based on a TVP-VAR(0.99,0.99) model with lag length of order 1 (BIC) and a 10-step-ahead forecast.