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Book

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On the propagation mechanism of international real interest rate spillovers: Evidence from more than 200 years of data*

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Abstract

This paper analyzes the real interest rate transmission mechanism across the United States, Japan, France, Germany, Holland, Italy, Spain and the United Kingdom during a period of more than 200 years. Based on a time-varying parameter vector autoregressive (TVP-VAR) connectedness methodology, the empirical results suggest that the magnitude of these international spillovers ranges between 30% and 75% across the sample period. Furthermore, it is shown that international interest rate spillovers increase during crisis periods, such as the two World Wars, the Great Depression of 1929, the 1980 and 1990 recessions, and the Great Financial Crisis of 2009. More interestingly, our findings illustrate the position of each of these eight countries as net transmitters or receivers of monetary policy shocks over time. Our analysis contributes to the debate on whether the conduct of monetary policy in a country should consider its international spillovers.

Keywords: Keywords: TVP-VAR, dynamic connectedness, extended joint connectedness, real interest rate dynamics.

JEL codes: C32, C52, E52.

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1 Introduction

In response of the Global Financial Crisis of 2009, central banks in developed economies (e.g., the US Federal Reserve, the European Central Bank, the Bank of England, or the Bank of Japan) reduced their policy interest rates to near zero and adopted several unconventional monetary policy measures. These monetary policy interventions directed to mitigate the consequences of the crisis within each of those countries had also significant consequences on other economies, confirming the importance of international monetary policy spillovers. For example, Brazil's finance minister declared in 2010 the existence of a "currency war" when interest rates were reduced to fight the GFC, while the Governor of the Reserve Bank of India in 2014 "wanted to draw attention to an area needed to be concerned about: the conduct of monetary policy in this integrated word" (Rajan, 2015). In this context, high and significant international monetary policy spillovers would justify an international policy coordination, while the benefits of international monetary policy coordination would be negligible in the case of insignificant international spillovers. This paper will contribute to this debate by examining the size of international interest rate spillovers across a sample of eight developed countries over a period of more than 200 years.

From a theoretical point of view, the size of international spillovers from monetary policy interventions will depend on the relative strength of each of the three following channels of transmission: the domestic macroeconomic conditions, the exchange rate channel, and the financial conditions. As far as the domestic macroeconomic conditions are concerned, monetary policy announcements in a country may reveal new information on the economic conditions of that country (Campbell et al., 2012; Nakamura and Steinsson, 2018), and this may lead investors to update their expectations about the macroeconomic conditions in other countries due to the various economic linkages among them (e.g., co-movements in business cycles, inflation dynamics). Spillovers can also occur through an exchange rate channel (Shambaugh, 2004). In this case, if a country wants to avoid large exchange rate adjustments against a major currency (i.e., for trade competitiveness or financial stability reasons), its policy rates should follow that of the larger economy. Finally, a third channel works through financial conditions. When capital markets are globally integrated, movements in term premia will spill to other countries through investors' portfolio allocations, motivated by a search for higher yields (Ammer et al., 2016). In this case, those investors searching for yield will shift funds from low-yielding bonds in economies with more expansionary policies to higheryielding bonds elsewhere, pushing these yields down. It should be mentioned that the intensity of these spillovers will have changed across countries over the last 200 years, a long period which includes different episodes, such as the classical gold standard from 1880 to 1914, the two World Wars, the years under the Bretton Woods system, the Global Financial Crisis of 2009 or the recent COVID-19 outbreak.

From an empirical point of view, interest rate spillovers have already been documented in the academic literature(among the many, Antonakakis et al., 2019; Chatziantoniou et al., 2020, 2021b; Gabauer et al., 2020). Dekle and Hamada (2015), for example, based on the estimation of several Vector Autoregressive (VAR) models, find that monetary expansions in Japan have positive output and inflation effects both within and across borders. In a national context, Rigobon and Sack (2003) estimate a structural-form GARCH model to reveal that there are strong contemporaneous interactions between interest rates and stock market returns across US financial markets. In an international context, Kalemli-Ozcan (2019) shows that US monetary policy has larger spillover effects in emerging countries than in advanced countries. In this framework, Georgiadis (2016), based on a VAR model, analyzes global output spillovers from US monetary policy and obtain that the magnitude of spillovers depends on several country characteristics, such as financial integration, trade openness, the exchange rate regime, or financial market development, among others. Similar results were found in Broda (2001); Edwards (2007); Martin and Rey (2006) or Dedola et al. (2017). While this literature mainly focuses on the impact of US international policy externalities on emerging countries (Kim, 2001; Canova, 2005; Maćkowiak, 2007; Dedola et al., 2017; Vicondoa, 2019), there is not so much literature that focuses on international interest rate spillovers across developed countries (Rogers et al., 2014; Chen et al., 2012).

Against this backdrop, the objective of this paper is to analyze the transmission of international real interest rate spillovers across the United States, the Euro Area, Japan and the United Kingdom during a period of more than 200 years of data based on a Bayesian time-varying parameter vector autoregressive (TVP-VAR) extended joint connectedness methodology (Balcilar et al., 2021). This paper contributes to the literature on international interest rate spillovers in a number of ways. First, the empirical study covers a period of more than 200 years of data, which includes different episodes and examples of different monetary policy interventions. Second, and as far as the methodology is concerned, this paper uses a Bayesian time-varying parameter vector autoregressive (TVP-VAR) extended joint connectedness methodology to calculate the degree of dynamic connectedness across the whole time period. As explained in Antonakakis et al. (2020), this method overcomes certain shortcoming of the connectedness measures proposed by Diebold and Yilmaz (2009, 2012); Diebold and Yılmaz (2014). The estimation of this dynamic index will allow us to infer how the degree of international spillovers has evolved over time, during the different episodes our sample period covers. For example, it will allow us to determine whether the relative size of these spillovers during the Great Depression in 1929, the Global Financial Crisis in 2008 or the recent COVID-19 outbreak. Third, our sample of countries include the US, countries in the Euro-Area (France, Germany, Holland, Italy, Spain), the UK, and Japan. The focus on this group of countries makes the analysis relevant as it includes the monetary policy interventions of the US Federal Reserve, the European Central Bank, the Bank of England or the Bank of Japan, together with those of each of these countries' central banks during certain time periods (i.e, before the establishment of the European Central Bank in 1998). Finally, our paper examines which countries have been the main transmitters (and receivers) of monetary policy shocks over the last 200 years.

Overall, our main results suggest real interest rate connectedness has almost doubled over the analyzed time period, implying that monetary policy spillovers are now significantly higher than they were prior 1918. Furthermore, our findings indicate that Germany, United States and Japan have increased their position as monetary policy transmitters in the more recent period.

The remainder of this paper is organized as follows. Section 2 provides a short overview of the employed dataset, Section 3 describes the empirical methodologies applied in the study whereas Section 4 illustrates the findings of the study and discusses the relevant arguments. Finally, Section 5 summarizes the key elements, provides a framework for policy implications, and concludes the study.

2 Data

This study employs an annual dataset of real interest rates for France, Germany, Holland, Italy, Japan, Spain, the UK, and the US primarily retrieved from Schmelzing (2020). The data, which use archival, printed primary and secondary sources, reconstruct global real interest rates on an annual basis going back to the 14th century. This dataset represents the most comprehensive history of the ex-post real (inflation-adjusted) interest rate. Our data spans over the period from 1800 to 2020, to ensure that we have a balanced data set for the eight countries, which cover on average 78% of Gross Domestic Product (GDP) of the advanced economies (Schmelzing, 2018). Note that, the data set of Schmelzing (2020) ends in 2018,[1] we updated it for two additional years to account for the effect of the ongoing COVID-19 pandemic by using comparable data from the Main Economic Indicators database of the Organisation for Economic Co-operation and Development (OECD). As the raw series are non-stationary according to Elliott et al. (1996) unit-root test we calculate the real interest rate changes. Those series are shown in Figure 1.

[Insert Figure 1 around here]

Table 1 shows that all real interest rate changes have increased on average over time. Furthermore, we see that countries such as Spain, Japan, Italy and France have highly volatile real interest rate changes whereas Germany, Holland, the UK and the US have less volatile ones. We also find suggestive evidence that the real interest rate changes of France, Italy, Japan, the UK and the US are significantly left skewed while the opposite is true for Germany, Holland and Spain. Additionally, all series are significantly leptokurtic distributed on the 1% significance level which supports the fact that all series are considered as non-normally distributed according to the (Jarque and Bera, 1980) normality test. In addition, all series are stationary (Dickey and Fuller, 1981), autocorrelated and exhibit ARCH errors (Fisher and Gallagher, 2012) on the 1% significance level. These findings provide supportive evidence that modeling the interdependencies using a TVP-VAR with time-varying variance-covariances is adequate. Finally, the unconditional correlations reveal that real interest rate changes are highest across European countries which make sense based on their geographical proximity. In the case of Japan only low correlations are detected.

[Insert Table 1 around here]

3 Methodology

The connectedness approach proposed by Diebold and Yilmaz (2009, 2012); Diebold and Yılmaz (2014) allows to monitor and evaluate the transmission mechanism within a predetermined network. This supports in general policymakers to adequately adjust economic and political strategies in order to mitigate adverse effects that propagate from shocks in specific variables/sectors. Hence, it is of essential importance that spillovers and the relative strength of shocks are accurately measured, monitored and investigated.

[1] The data is available for download from: https://www.bankofengland.co.uk/working-paper/2020/eight-centuries-of-global-real-interest-rates-r-g-and-the-suprasecular-decline-1311-2018.

The relevance and applicability of this framework already led to multiple improvements and extensions overcoming two major shortcomings which are that (i) the original dynamic approach rests on a rolling-window VAR – that requires to choose a rolling window size – and (ii) on a sub-optimal GFEVD normalization technique (Caloia et al., 2019). The first issue has been tackled by Antonakakis et al. (2020) who propose a TVP-VAR based connectedness approach to (i) overcome the arbitrarily chosen VAR window size, (ii) be less sensitive to outliers, (iii) to monitor more accurately the parameter changes, and (iv) avoid the loss of observations. A solution for the second shortcoming has been suggested by Lastrapes and Wiesen (2021) who derived a normalization method based upon the goodness-of-fit measure R^2. Their so-called joint spillover index lead to a more natural interpretation of connectedness measures and also to a more accurate illustration of the propagation mechanism at hand. These two concepts have been combined and extended in Balcilar et al. (2021) who further enabled to investigate net pairwise directional connectedness measures in a joint connectedness setting which has previously not been possible. Additionally, the TVP-VAR based extended joint connectedness approach includes all aforementioned advantages over the original connectedness approach of Diebold and Yilmaz (2009, 2012).

Exploring the international real interest rate propagation mechanism among France, Germany, Holland, Italy, Japan, Spain, the UK and the US, requires to estimate a TVP-VAR model[2] – with a lag length of order one, as suggested by the Bayesian information criterion (BIC), – which can be outlined as follows,

$$\boldsymbol{y}_t = \boldsymbol{B}_t \boldsymbol{y}_{t-1} + \boldsymbol{\epsilon}_t \qquad \boldsymbol{\epsilon}_t \sim N(\boldsymbol{0}, \boldsymbol{\Sigma}_t) \tag{1}$$

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

where $\boldsymbol{y}_t$, $\boldsymbol{y}_{t-1}$ and $\boldsymbol{\epsilon}_t$ are $K \times 1$ dimensional vector and $\boldsymbol{B}_t$ and $\boldsymbol{\Sigma}_t$ 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, the TVP-VAR is transformed to a TVP-VMA according to the Wold representation theorem: $\boldsymbol{y}_t = \sum_{h=0}^{\infty} \boldsymbol{A}_{h,t} \boldsymbol{\epsilon}_{t-i}$ where $\boldsymbol{A}_0 = \boldsymbol{I}_K$.

[2] 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 Antonakakis et al. (2020).

3.1 TVP-VAR based connectedness approach

We continue with the TVP-VAR based connectedness approach as of Antonakakis et al. (2020) to better understand the intuition and terminology of the TVP-VAR extended joint connectedness approach. This framework is based upon the H-step ahead generalized forecast error variance decomposition (GFEVD) (Koop et al., 1996; Pesaran and Shin, 1998) which represents the effect a shock in series j has on series i. This can be mathematically formulated as follows:

$$\phi_{ij,t}^{gen}(H) = \frac{\sum_{h=0}^{H-1}(\boldsymbol{e}_i'\boldsymbol{A}_{ht}\boldsymbol{\Sigma}_t\boldsymbol{e}_j)^2}{(\boldsymbol{e}_j'\boldsymbol{\Sigma}_t\boldsymbol{e}_j)\sum_{h=0}^{H-1}(\boldsymbol{e}_i'\boldsymbol{A}_{ht}\boldsymbol{\Sigma}_t\boldsymbol{A}_{ht}'\boldsymbol{e}_i)} \tag{3}$$

$$gSOT_{ij,t} = \frac{\phi_{ij,t}^{gen}(H)}{\sum_{k=1}^{K}\phi_{ik,t}^{gen}(H)} \tag{4}$$

where $\boldsymbol{e}_i$ is a $K \times 1$ zero selection vector with unity on its ith position and $\phi_{ij,t}^{gen}(H)$ is the unscaled GFEVD ($\sum_{j=1}^{K}\zeta_{ij,t}^{gen}(H) \neq 1$). Based upon the work of Diebold and Yilmaz (2009, 2012) the unscaled GFEVD is normalized to unity by dividing it by the row sum which leads to the scaled GFEVD, $gSOT_{ij,t}$.

The scaled GFEVD is the fundament on which all connectedness measures are calculated. The total directional connectedness from all others to series i and the total directional connectedness to all others from a shock in series i that represent by how much the network influences series i and how much series i influences the predetermined network, respectively, can be calculated as follows:

$$S_{i\leftarrow\bullet,t}^{gen,from} = \sum_{j=1,i\neq j}^{K} gSOT_{ij,t} \tag{5}$$

$$S_{i\rightarrow\bullet,t}^{gen,to} = \sum_{j=1,i\neq j}^{K} gSOT_{ji,t} \tag{6}$$

Based upon the previous two measures the net total directional connectedness of series i can be computed. This measure is interpreted as the net influence of series i on the network,

$$S_{i,t}^{gen,net} = S_{i\rightarrow\bullet,t}^{gen,to} - S_{i\leftarrow\bullet,t}^{gen,from}. \tag{7}$$

If $S_{i,t}^{gen,net} > 0$ ($S_{i,t}^{gen,net} < 0$), series i is influencing (influenced by) all others more than being influenced by (influencing) them and thus is considered as a net transmitter (receiver) of shocks indicating that series i is driving (driven by) the network.

At the centre of the connectedness approach lies the total connectedness index (TCI) which highlights the network interconnectedness and hence average network spillover. The TCI is calculated as the average total directional connectedness from (to) others:

$$gSOI_t = \frac{1}{K}\sum_{i=1}^{K} S^{gen,from}_{i\leftarrow\bullet,t} = \frac{1}{K}\sum_{i=1}^{K} S^{gen,to}_{i\rightarrow\bullet,t}, \tag{8}$$

A high (low) value implies that the market risk is high (low).

Finally, the connectedness approach provides also information on the bilateral level by means of the net pairwise directional connectedness which illustrates the bilateral power between series i and j,

$$S^{gen,net}_{ij,t} = gSOT^{gen,to}_{ji,t} - gSOT^{gen,from}_{ij,t}. \tag{9}$$

If $S^{gen,net}_{ij,t} > 0$ ($S^{gen,net}_{ij,t} < 0$), series i dominates (is dominated) series j which means that series i influences (is influenced by) series j more than being influenced by it.

3.2 TVP-VAR Based Extended Joint Connectedness Approach

The main difference between the extended joint and the original connectedness approach is that the normalization method is not chosen arbitrarily but derived from the popular R^2 goodness-of-fit measure[3]. $S^{jnt,from}_{i\leftarrow\bullet,t}$ represents the impact all series j have on series i. This can be mathematically formulated by:

$$\boldsymbol{\xi}_t(H) = \boldsymbol{y}_{t+H} - E(\boldsymbol{y}_{t+H}|\boldsymbol{y}_t, \boldsymbol{y}_{t-1}, ...) = \sum_{h=0}^{H-1} \boldsymbol{A}_{h,t}\boldsymbol{\epsilon}_{t+H-h} \tag{10}$$

$$E(\boldsymbol{\xi}_t(H)\boldsymbol{\xi}'_t(H)) = \boldsymbol{A}_{h,t}\boldsymbol{\Sigma}_t\boldsymbol{A}'_{h,t} \tag{11}$$

$$S^{jnt,from}_{i\leftarrow\bullet,t} = \frac{E(\xi^2_{i,t}(H)) - E[\xi_{i,t}(H) - E(\xi_{i,t}(H))|\epsilon_{\forall\neq i,t+1}, ..., \epsilon_{\forall\neq i,t+H}]^2}{E(\xi^2_{it}(H))} \tag{12}$$

$$= \frac{\sum_{h=0}^{H-1} \boldsymbol{e}'_i\boldsymbol{A}_{ht}\boldsymbol{\Sigma}_t\boldsymbol{M}_i(\boldsymbol{M}'_i\boldsymbol{\Sigma}_t\boldsymbol{M}'_i)^{-1}\boldsymbol{M}'_i\boldsymbol{\Sigma}_t\boldsymbol{A}'_{ht}\boldsymbol{e}_i}{\sum_{h=0}^{H-1} \boldsymbol{e}'_i\boldsymbol{A}_{ht}\boldsymbol{\Sigma}_t\boldsymbol{A}'_{ht}\boldsymbol{e}_i} \tag{13}$$

where $\boldsymbol{M}_i$ is a $K \times K-1$ rectangular matrix that equals the identity matrix with the ith column eliminated, and $\boldsymbol{\epsilon}\forall \neq i$, $t+1$ denotes the $K-1$-dimensional vector of shocks at time $t+1$ for all

[3]For the detailed mathematical derivations interested readers are referred to the technical appendix of original study of Lastrapes and Wiesen (2021).

series except series i. In a next step, the joint total connectedness index is calculated as follows,

$$jSOI_t = \frac{1}{K}\sum_{i=1}^{K} S^{jnt,from}_{i\leftarrow\bullet,t} \tag{14}$$

which is within zero and unity opposed to the TCI of the originally proposed approach as discussed in Chatziantoniou and Gabauer (2021) and Gabauer (2021).

An important extension of Balcilar et al. (2021) compared to Lastrapes and Wiesen (2021) is that instead of a single scaling factor multiples are used to link $gSOT$ to $jSOT$:

$$\lambda_{it} = \frac{S^{jnt,from}_{i\leftarrow\bullet,t}}{S^{gen,from}_{i\leftarrow\bullet,t}} \tag{15}$$

$$jSOT_{ij,t} = \lambda_{it} gSOT_{ij,t} \tag{16}$$

Based upon this equality the net pairwise directional connectedness measures can be calculated as well:

$$S^{jnt,to}_{i\rightarrow\bullet,t} = \sum_{j=1,i\neq j}^{K} jSOT_{ji,t} \tag{17}$$

$$S^{jnt,net}_{j,t} = S^{jnt,to}_{i\rightarrow\bullet,t} - S^{jnt,from}_{\bullet\rightarrow i,t} \tag{18}$$

$$S^{jnt,net}_{ij,t} = jSOT^{jnt,to}_{ji,t} - jSOT^{jnt,from}_{ij,t}. \tag{19}$$

4 Empirical results

In this section, we present the averaged dynamic connectedness measures based upon the extended joint connectedness framework of Balcilar et al. (2021). For comparison purposes, we include the results obtained from the standard TVP-VAR connectedness approach (Antonakakis et al., 2020). Please keep in mind that the TVP-VAR extended joint connectedness approach is a refined version of the standard TVP-VAR connectedness approach as it uses a theoretically derived normalization technique as outlined in Lastrapes and Wiesen (2021). In this regard, we anticipate results to be qualitatively similar with the joint connectedness method though providing more adequately-justified and thus more accurate results. Finally, it should be mentioned that even though the averaged connectedness results sketch an overview of the real interest rate transmission mechanism, it is time-invariant and might mask economic event driven effects that will be revealed in a later step when discussing the dynamic connectedness plots.

We begin by considering the averaged dynamic connectedness results which are given by Table 2. The main diagonal elements correspond to the own-variance share which is the proportion that is explained by its own lagged dynamics whereas off-diagonal values demonstrate the contribution of other variables. We find that the average TCI is quite substantial as it is equal to 43.12% meaning that on average 43.12% of a shock in one variable spills over to all others. Interestingly, Holland (16.22%), Italy (25.99%), Japan (5.01%) and the US (12.70%) are on average the main transmitters of shocks while France (-28.28%), Germany (-7.20%), Spain (-0.25%) and the UK (-24.19%) are on average the main receiver of shocks. France mainly absorbs shocks from Holland (12.07-6.94=5.13%), Italy (21.02-3.61=17.41%) and the US (12.43-5.43=7.00%) while Germany is primarily affected by Holland (23.60-17.01=6.59%). Apparently, Japan dominates the UK (6.13-4.14=1.99%) and the US (7.81-7.55=0.26%) on the net transmission basis. Further notable results are that the UK is driven by shocks from Holland (18.81-9.41=9.40%) and the US (10.52-6.62=3.90%).

[INSERT TABLE 2 AROUND HERE]

We carry on with the description of the dynamic total connectedness which represents the market interconnectedness across time. Figure 2 shows that the connectedness of this network ranges between 30% and 75%. Additionally, a jump in the market risk to a new plateau is observed after 1918. The plot also highlights various important economic and political events such as the first major peak in 1918 which might be caused by World War I in combination with the Spanish flu that killed millions globally. Another pronounced spike is shown around 1930 caused by the Great Depression which lasted a whole decade. Additionally, the dynamic connectedness also marks World War II and its aftermath as well as the early 1980 and 1990 recessions. Notably, the market connectedness decreased substantially after the Global Financial Crisis of 2009. Nonetheless and besides the economic-event dependence of the dynamic total connectedness, the most important result is that over the years real interest rate interconnectedness almost doubled. This implies that nowadays national monetary policy has a far more global impact than it had prior 1918.

[INSERT FIGURE 2 AROUND HERE]

To obtain concrete evidence that real interest rate connectedness seems to be higher during episodes of crises, we regressed the TCIs on the BCDI index of Reinhart et al. (2009), which is a function of four types of crises namely, banking, currency, sovereign default and inflation covering a total of 66 countries that account for about 90% of the world's GDP. The index is available from 1800 to 2010.[4] We found that the coefficients of the response of the TCIs of Balcilar et al. (2021) and Antonakakis et al. (2020) to the BDCI index was positive (with values of 0.16 and 0.17 respectively) and significant at the 1% level. When we looked at the BDCI+ index of Reinhart et al. (2009), which now included stock market crashes, and covered the period of 1863 to 2010, we again found a positive and significant effect (at 1% level) of this index on the two TCIs considered (with coefficient values of 0.11 in both cases).[5]

We continue to focus on Figure 3 that illustrates the net transmitting position of each series over time. To put differently, Figure 3 depicts whether any series of the particular network assumes either a net transmitting or net receiving role across the given sample period. It should also be mentioned that switching roles over the last 200 years can be expected as the economic and financial system has changed substantially over this period.

Figure 3 presents that France has been a receiver of shock throughout the period of analysis with the exception of the World War I period when it became a transmitter of shocks. Italy has mainly been a net transmitter of shocks besides a longer period of time that covers both World Wars. Contrary to the net transmission behavior of Italy, the UK has been mainly a net transmitter of shocks throughout the whole sample period except during both World Wars when it has assumed a net receiving role. Spain has been almost neutral until the start of World War I when it receives substantial shocks from all others until the end of World War II when Spain transmitted more shocks to others than it received. This behavior ended in 1980. Since then it has been a net receiver of shocks until the end of the sample period. The case of Holland is quite interesting as Holland has driven the market until the end of World War II. From then onwards, Holland has been on the receiving end until 1990 when it started dominating the market again, however, on a smaller scale far from the time prior World War II. Japanese real interest rate changes have been

[4]The crisis data is available for download from: http://www.carmenreinhart.com/data/browse-by-topic/topics/8/.

[5]Since the BDCI and BDCI+ indexes ended in 2010, we also considered the dummy variable of global financial crises as identified in Table A2 of Boubaker et al. (2020), to which we added dummies for the two World Wars and the COVID-19 pandemic. Consistent with the BDCI and BDCI+ index results, the dummy variable was found to positively (7.94 and 8.61) and significantly (at the 1% level) increase the two TCIs (of Balcilar et al. (2021) and Antonakakis et al. (2020) respectively) considered. As an additional analysis, using the approach of Chatziantoniou et al. (2021a), we decomposed the TCI into short-, medium-, and long-run components, and found that BDCI and BDCI+ positively and significantly (at the 1% level) affects the medium- (with values 0.05 in both instances) and long-run (with values of 0.02 in both cases) components, but not the short-term one. Further details of these results are available upon request from the authors.

mainly influenced during both World Wars. While Japan has largely been affected by the market throughout the First World War, it has been on the net transmitting end since the beginning of the Second World War. Remarkable is the evolution of the German real interest rate changes. From the beginning of the sample period until the First World War, Germany has been a net receiver of shocks while it has become a dominant market player throughout the both World Wars. Since then the German market has slightly been driven by the others until 1990 which marks the German reunification. From this point onwards, the German real interest rate changes has become a significant net transmitter of shocks. Last but not least the US real interest rate has become more dominant over time. The only two periods in which the US has been a net receiver of shocks are those highlighting both World Wars, however, since the end of the Second World War the dominance of the US market increased until very recently when the Global Financial Crisis of 2009 and its aftermath hit the American economy.

[INSERT FIGURE 3 AROUND HERE]

5 Conclusions

This paper analyzes the real interest rate transmission mechanism across the United States, Japan, France, Germany, Holland, Italy, Spain and the United Kingdom during a period of more than 200 years. Based on a time-varying parameter vector autoregressive (TVP-VAR) extended joint connectedness methodology (Balcilar et al., 2021), we find a quite substantial degree of international interest rate spillovers with an average TCI equal to 43.12% over the entire time period, which implies that, on average, 43.12% of a shock in one interest rate spills over to all other rates. Furthermore, the results suggest that Holland, Italy, Japan and the US have been on average the main transmitters of shocks over the period, while France, Germany, Spain and the UK have been the main receiver of shocks, indicating the prominent roles of the monetary interventions of the US Federal Reserve or the Bank of Japan in an international context over the last two centuries.

More interestingly, the empirical analysis shows that the dynamic total connectedness steadily increased from 30% at the beginning of the sample period to around 50%. Furthermore, we find that the network interconnectedness is economic-event driven as it increased during both World Wars, during the early 1990 recession and reached a peak around the Global Financial Crisis of 2009. This is in line with the general finding in the academic literature that global crisis trigger an increase in the connectedness among financial prices (Zhang and Wei, 2010; Ahmadi et al., 2016; Kang et al., 2017), implying that diversification opportunities decrease in periods of crisis. As far as the interest rates are concerned, this result also implies that monetary policy interventions in a country will have more severe effects in other countries in periods of crisis. Nonetheless and besides the economic-event dependence of the connectedness index, the most essential finding is that over the years real interest rate interconnectedness almost doubled. Hence, national monetary policy has nowadays a far more global impact than it had prior 1918.

Finally, this paper illustrates the position of each of the eight countries as net receiver/transmitter of real interest rate shocks over time, which can be taken as a proxy of the relative international dominance over time. The results suggests that Italy has been mainly a transmitter of shocks, except the time that covers both World Wars, while, on contrary, France and the UK have been net receivers of shocks except during the interwar period. It is interesting to highlight the cases of Germany, the US and Japan. Until WWI, Germany has been a receiver of shocks, while from the German reunification in 1990, the interest rate in this country has become a relevant transmitter of shocks, pointing to the increasing international relevance of this country's monetary policy interventions. As far as the Japanese case is concerned, while this country's interest rate has been a net receiver of shocks until WWII, it switched its position and became a net transmitter of shocks after this period. Finally, we also observe that the US interest rates have become more dominant over time.

Important policy implications can be derived from the empirical results obtained in this paper. According to our results, real interest rate interconnectedness has almost doubled over the last 200 years, implying that monetary policy interventions have nowadays far more international consequences than at the beginning of the 20th century. Hence, this result suggests that the benefits of international monetary policy coordination are nowadays higher than ever. Furthermore, these benefits increase in periods of economic crises. Finally, our results suggest that interest rates in Germany, Japan and the US have expanded their role as main transmitters of shocks over time. Based on these findings, our paper suggest that monetary policy authorities, specially the European Central Bank, the Bank of Japan and the US Federal Reserve, should take into account the international spillovers generated with each of their interventions.

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Table 1: Summary Statistics

	France	Germany	Holland	Italy	Japan	Spain	UK	US
Mean	0.85	3.40	3.39	1.87	0.80	7.38	2.17	2.73
Variance	126.63	60.58	34.24	169.92	207.44	279.89	42.15	33.92
Skewness	-2.91***	0.45***	0.40**	-3.20***	-0.85***	0.85***	-0.72***	-0.33**
	(0.00)	(0.01)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)
Excess	13.66***	2.93***	2.26***	16.64***	3.62***	4.54***	4.73***	2.30***
Kurtosis	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
JB	2021.58***	86.19***	52.44***	2912.67***	146.59***	215.66***	224.13***	52.25***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
ADF	-5.81***	-10.91***	-7.44***	-6.79***	-10.56***	-6.45***	-10.16***	-7.53***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$Q(20)$	208.61***	45.07***	144.12***	106.04***	43.61***	334.06***	57.65***	59.45***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$Q^2(20)$	168.11***	72.78***	110.07***	42.53***	33.04***	259.20***	64.74***	37.92***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	France	Germany	Holland	Italy	Japan	Spain	UK	US
France	1.00	0.27	0.43	0.37	0.05	0.33	0.32	0.30
Germany	0.27	1.00	0.42	0.21	0.09	0.06	0.29	0.14
Holland	0.43	0.42	1.00	0.39	0.09	0.28	0.47	0.24
Italy	0.37	0.21	0.39	1.00	0.09	0.26	0.32	0.25
Japan	0.05	0.09	0.09	0.09	1.00	0.03	0.13	0.16
Spain	0.33	0.06	0.28	0.26	0.03	1.00	0.31	0.28
UK	0.32	0.29	0.47	0.32	0.13	0.31	1.00	0.28
US	0.30	0.14	0.24	0.25	0.16	0.28	0.28	1.00

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; ADF: Dickey and Fuller (1981) unit-root test; $Q(20)$ and $Q^2(20)$: Fisher and Gallagher (2012) weighted Portmanteau test.

Table 2: Averaged Connectedness Table

	France	Germany	Holland	Italy	Japan	Spain	UK	US	FROM others
France	39.81 (42.96)	4.63 (4.40)	12.07 (11.50)	21.02 (19.76)	3.59 (3.4)	1.4 (1.36)	5.06 (4.87)	12.43 (11.75)	60.19 (57.04)
Germany	3.37 (2.93)	48.48 (56.73)	23.6 (20.10)	7.5 (6.08)	2.3 (1.88)	1.49 (1.23)	4.76 (4.09)	8.51 (6.95)	51.52 (43.27)
Holland	6.94 (6.46)	17.01 (15.8)	39.35 (43.95)	7.24 (6.81)	5.85 (5.30)	4.25 (3.90)	9.95 (9.07)	9.41 (8.71)	60.65 (56.05)
Italy	3.61 (4.45)	5.11 (4.84)	3.45 (4.15)	78.86 (77.01)	0.95 (0.99)	0.94 (1.04)	3.68 (3.96)	3.41 (3.55)	21.14 (22.99)
Japan	3.84 (4.43)	2.2 (2.55)	3.55 (4.1)	2.33 (2.62)	75.89 (72.51)	0.5 (0.56)	4.14 (4.81)	7.55 (8.43)	24.11 (27.49)
Spain	2.38 (2.76)	1.49 (1.80)	5.88 (6.99)	3.4 (3.46)	2.49 (3.17)	77.26 (73.33)	2.38 (3.17)	4.73 (5.32)	22.74 (26.67)
UK	6.34 (6.20)	7.55 (7.48)	18.81 (18.4)	2.82 (2.82)	6.13 (5.79)	8.61 (8.55)	39.23 (40.48)	10.52 (10.29)	60.77 (59.52)
US	5.43 (5.64)	6.34 (6.42)	9.51 (9.79)	2.82 (2.89)	7.81 (8.02)	5.32 (5.49)	6.62 (6.94)	56.15 (54.8)	43.85 (45.20)
TO others	31.91 (32.88)	44.32 (43.29)	76.87 (75.02)	47.14 (44.43)	29.12 (28.56)	22.49 (22.13)	36.59 (36.91)	56.54 (55.00)	TCI)
NET	-28.28 (-24.16)	-7.20 (0.02)	16.22 (18.97)	25.99 (21.45)	5.01 (1.06)	-0.25 (-4.54)	-24.19 (-22.61)	12.70 (9.80)	43.12 (42.28)

Notes: Results are based on the TVP-VAR(1) extended joint connectedness approach (Balcilar et al., 2021) with a 60-step-ahead generalized forecast error variance decomposition. Values in parantheses represent the results of the TVP-VAR(1) based connectedness approach (Antonakakis et al., 2020).

Figure 1: First differenced real interest rates

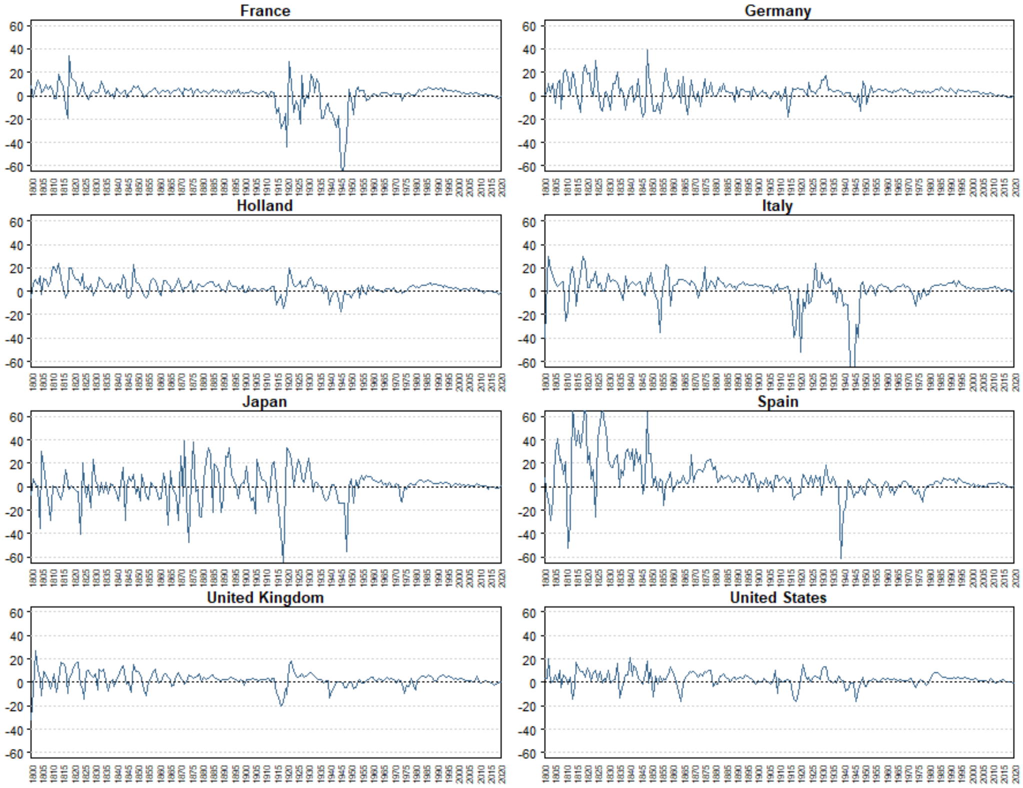
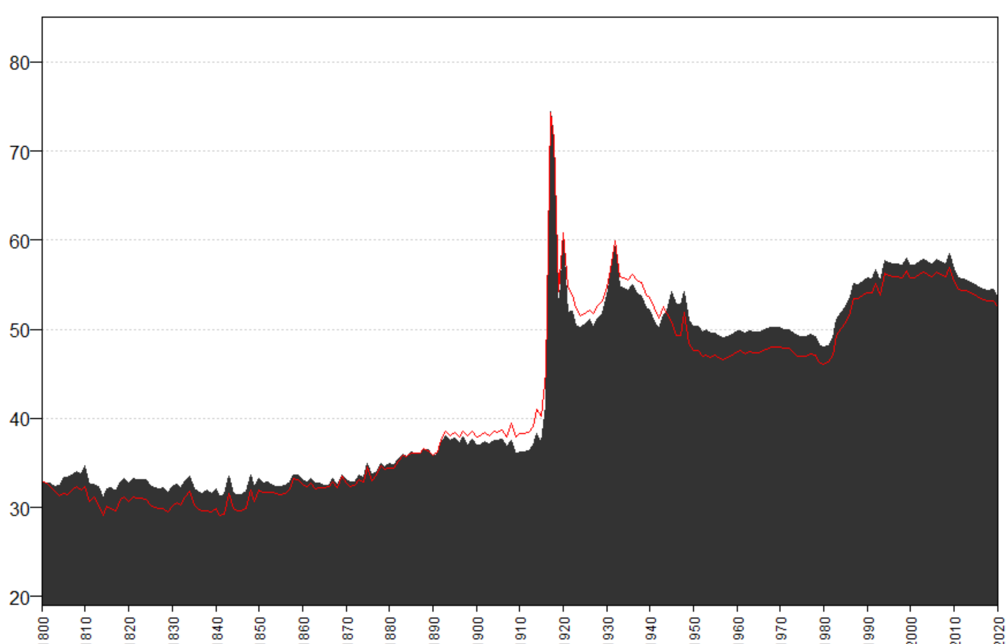
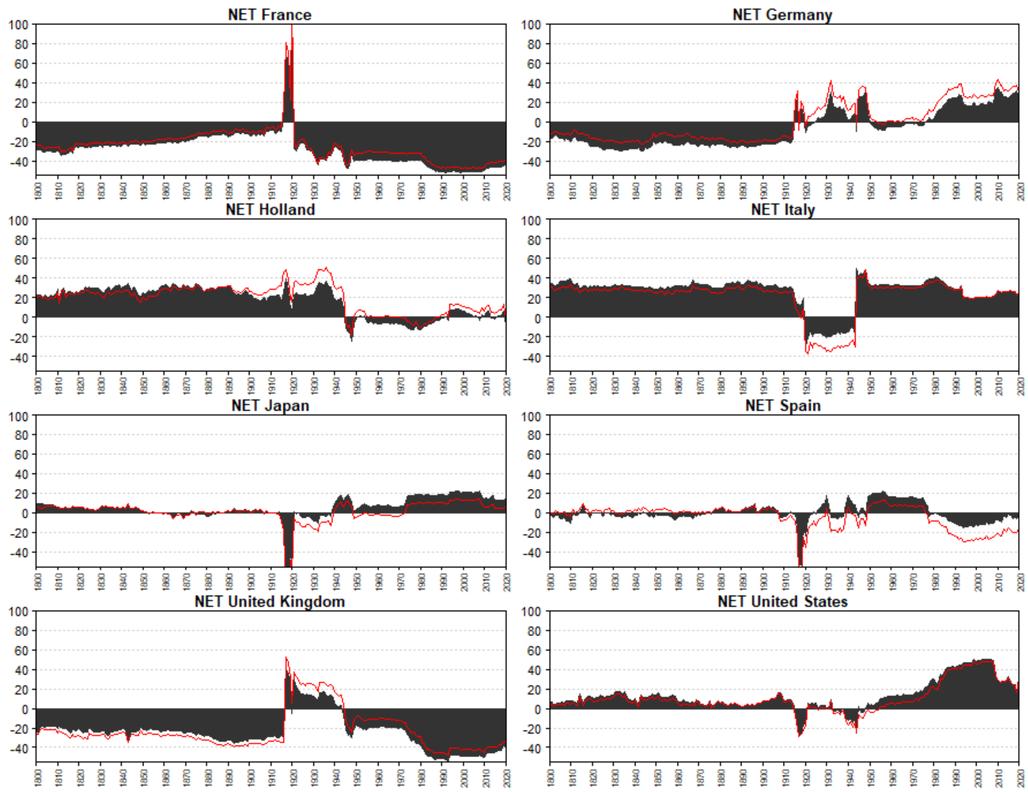


Figure 2: Dynamic Total Connectedness



Notes: Results are based on the TVP-VAR(1) extended joint connectedness approach (Balcilar et al., 2021) with a 60-step-ahead generalized forecast error variance decomposition. The red line illustrates the results of the TVP-VAR(1) based connectedness approach (Antonakakis et al., 2020).

Figure 3: Net Total Directional Connectedness



Notes: Results are based on the TVP-VAR(1) extended joint connectedness approach (Balcilar et al., 2021) with a 60-step-ahead generalized forecast error variance decomposition. Red lines illustrate the results of the TVP-VAR(1) based connectedness approach (Antonakakis et al., 2020).