

Belke, Ansgar; Dubova, Irina

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International spillovers in global asset markets*

by

Ansgar Belke

(University of Duisburg-Essen, Centre for European Policy Studies, Brussels, and Institute for the Study of Labor, Bonn)

and

Irina Dubova

(University of Duisburg-Essen and Ruhr Graduate School, Essen)

Brussels and Essen

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Abstract

The paper estimates the financial transmission between bond and equity markets within and between across the four largest global financial markets - the United States, the Euro area, Japan, and the United Kingdom. In a globalized world, where the complex transmission process across various financial assets is not restricted to just domestic market, we argue that international bond and equity markets are highly interconnected both within and across asset classes. This paper uses identification through generalized forecast error variance decompositions to estimate spillovers across four systemic markets in a vector autoregression framework. We find that asset prices react strongest to international shocks within the same asset class, but there are also substantial international spillovers across asset classes. Rolling estimations analysis provides evidence that global asset markets have become more integrated over time and the bilateral relationships change over time.

JEL codes: E52, E58, F42

Keywords: asset markets, financial transmission, financial market integration, rolling estimations, spillovers, vector autoregression

Corresponding author: Irina Dubova, University of Duisburg-Essen, Campus Essen, Universitaetsstraße 12, D-45117 Essen, Germany, e-mail: irina.dubova@uni-due.de.

1. Introduction

The global financial markets have become increasingly integrated and highly complex, with cross-border interconnections and interdependencies. A thorough analysis of these interrelationships is needed for the understanding and managing of the financial risks in the increasingly connected global environment.

The turbulence in asset markets during the global financial crisis (GFC) has caused manifold debates about asset market interlinkages across countries, with a particular interest on spillovers originating from US financial shocks. Moreover, it initiated discussions about whether these interlinkages are different in times of financial crisis compared to non-crisis times. The subsequent Euro area debt crisis resulted in global financial volatility as well, although to a lesser extent than the GFC. Thus, a new strand of research was dedicated to the analysis of broader linkages among advanced (as well as emerging countries) financial markets (Bayoumi and Bui, 2012; Beirne and Gieck, 2014; Raddant and Kennet, 2016).

The recent interest in financial spillovers is clearly related to the current tightening of the Fed's monetary stance, which is likely to create non-negligible spillovers for the other countries such as the Euro area, UK and Japan, among others (Buitron and Vesperoni, 2015, Horvath, 2016, IMF, 2014). Rising interest rates in the United States are likely to spill over, leading to higher interest rates in the rest of the world for the following reasons. Firstly, higher expected returns in the United States may entail portfolio shifts toward US assets as international investors may draw capital from other countries, thereby creating upward pressure on yields there (Belke et al., 2014). Secondly, Gürkanyak and Wright (2012) argue that market participants may expect the central bank to have some private information about the state of the global business cycle. Thus, the policy actions of the Fed may signal this information to international market participants. This causes them to update their beliefs about the state of the global economy as well as about the potential policy actions of their domestic central banks. Thirdly, the pass-through of an appreciated US dollar to non-US prices may lead to inflationary pressure and output growth via expenditure-switching in other countries, thereby prompting increases in

non-US interest rates (Bernoth and Koenig, 2016). It is important to note that spillovers may take place independent of the exchange rate regime (for the related arguments see Belke and Rees, 2014).

The identification of complex financial market spillovers is a challenging econometric issue. Firstly, an empirical framework is expected to examine the various transmission channels simultaneously. Secondly, the model should take into account highly contemporaneous correlations in the data, so that the causal relationships and the size of spillovers are identified in a proper way. This paper investigates the interconnectedness among systemic bond and equity markets of the United States, the Euro area, the United Kingdom and Japan, using the spillover measures proposed by Diebold and Yilmaz (2012) based on generalized VAR forecast error variance decompositions.

The remainder of this paper is organized as follows. Section 2 reviews the literature on domestic and on international financial linkages and integration. Section 3 outlines our estimation approach and the data and variables we use. Section 4 presents our estimations of spillovers, followed by robustness checks in Section 5. Section 6 sums up our findings and discusses policy implications.

2. Related Literature

Financial markets have become increasingly integrated, both domestically and internationally as well as within and between different asset classes. But what is the dominant pattern excavated by the leading literature in the field? Diebold and Yilmaz (2009) provide evidence that return and volatility spillovers across equity markets in 19 different countries exist and vary widely. However, Bekaert et al. (2010) refutes the presence of cross-border contagion in international equity markets. Related to that, the research of Diebold and Yilmaz (2012) highlights the importance of the volatility spillovers across equity, bond, currency and commodity markets in US.

Ehrmann et al. (2011) underline the importance of international spillovers by analyzing the financial integration and the transmission channels in the period 1989–2008 for seven asset prices: short-term interest rates, bond yields and equity market returns as well as the exchange rate in the USA and the Euro area. They find that US financial markets explain on average around 30 percent of euro area financial market movements in the period 1989–2004, whereas Euro area markets in turn account for only about 6 percent of the variance of US asset prices. Moreover, the direct transmission of financial shocks within asset classes is often amplified substantially through indirect spillovers via other asset prices.

Bayoumi and Bui (2012) examine spillovers within bond market and within equity market in the separate models for the world's most important markets, i.e. those of the U.S., the Euro area, Japan, and the UK in the period from 2000 to 2009. Their results suggest that U.S. bond and equity market shocks reverberate around the world much more than shocks originating in other areas. The European markets, however, appear to have two-way spillovers on each other and there is some evidence that Euro area shocks also impact Japan. Moreover, Japanese spillovers are generally the weakest across the markets that are examined.

Beirne and Gieck (2012) analyze bond, stock and currencies markets by means of GVAR model for over 60 economies for the period 1998-2011. Their results suggest a high significance of within-market effects for each asset market in advanced economies.

For the Euro area, Chinn and Frankel (2003) show that prior to the creation of European Monetary Union (EMU) European rates were strongly affected by interest rate changes in the United States, whereas the effects became more ambiguous in the early stages of the Euro when US rates were influenced by Euro area rates as well. A number of studies are dedicated to the monetary policy spillovers (e.g. Caceres et al., 2016) as well as interactions of monetary policy and financial markets (e.g. Rigobon and Sack, 2003). Using the GVAR framework Dees et al. (2007) find that US financial shocks are transmitted rapidly to Euro area and that the equity and bond markets are highly synchronous. However, the changes in US short-term interest rates have only negligible effects on Euro area's short-term rates. Eijffinger (2008) finds evidence that it is generally the US interest rate (at both the short and long horizon) that adjusts in order to close interest differentials between the US and the Euro area, whereas the Euro area rates

hardly move. Thus, Eijffinger concludes that there exist statistically significant (“error-correcting”) interdependencies between the Euro area and the US.

3. Data and empirical approach

3.1 Data

We analyze four systemic financial markets – the United States, the Euro area, the United Kingdom and Japan. They are considered as the most advanced and integrated financial markets and represent the majority share of the world market capitalization (Bayoumi and Bui, 2012). Our main focus lies on the international interactions (spillovers) of bond and stock markets, whereas the specifications which also include money markets and foreign exchange markets are discussed and presented as robustness checks in section 5.

The two-day frequency of data was chosen for several reasons. On the one hand, it reduces the issue of the different opening and closing times across the day in different countries. On the other hand, using high-frequency data, whose dynamics are by nature not affected by macroeconomic fundamentals, should have an advantage in identifying the spillovers in financial markets where the news are priced in rapidly. Additionally, by using high-frequency data, we have sufficient observations for conducting time-constancy analysis.

We assume that financial markets are by nature forward-looking, so they already include the expected component of macroeconomic conditions. The main objective of our analysis is to identify which markets drive high underlying correlations. Hence, for more accurate identification one needs to take into account common shocks to the system as well. In our investigation we will consider three major common shocks which stem from global risk aversion, oil prices and stock developments in emerging markets. As shown in Miranda-Agrippino and Rey (2015) the global financial cycle is highly negatively correlated with “market fear” measures. This means that the inclusion of the Chicago Board Options Exchange (CBOE) volatility index should control for the common global financial cycle shocks. Horvath (2015) highlights the importance of oil prices and economic performance in emerging markets for the monetary

policy spillovers between US and Euro area. Beirne and Gieck (2012) stress the important role of emerging market economies as well. Ehrmann et al. (2011) also mention that although being neglected in their analysis, the Asian markets, among others, might be of relevance for bilateral US–Eurozone financial relationships.

Figure 1 below presents the development of the 10-year government bond yields for the US, the Euro area, the UK and Japan over time. Figure 2 plots the development over time of the stock indices – the S&P 500 for US, the S&P Euro for Euro area, the FTSE 250 for the UK and the NIKKEI for Japan. The sample under consideration ranges from 3.01.1995 to 31.10.2016. Our data source is Thomson Reuters Datastream.

Figure 1. Bond markets in US, EA, UK, and Japan over time

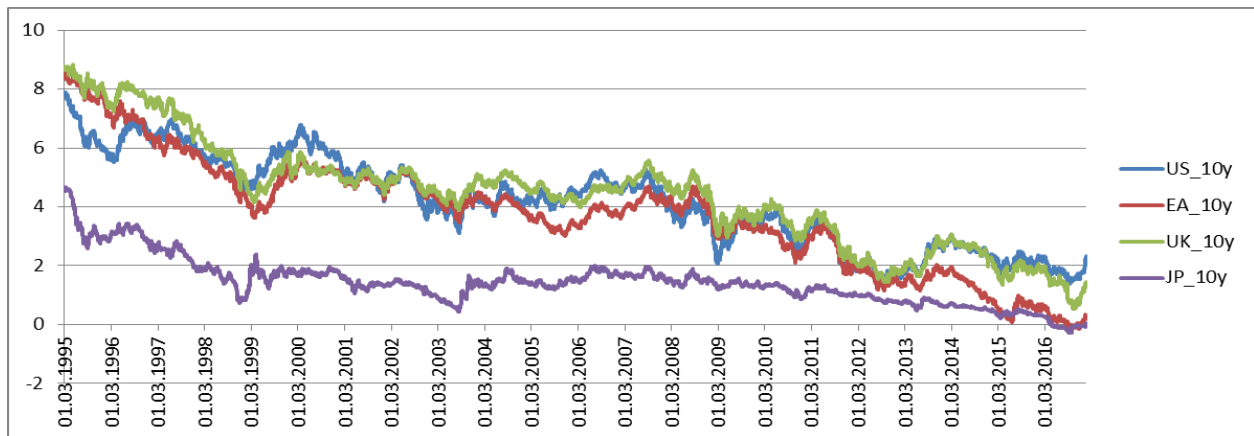
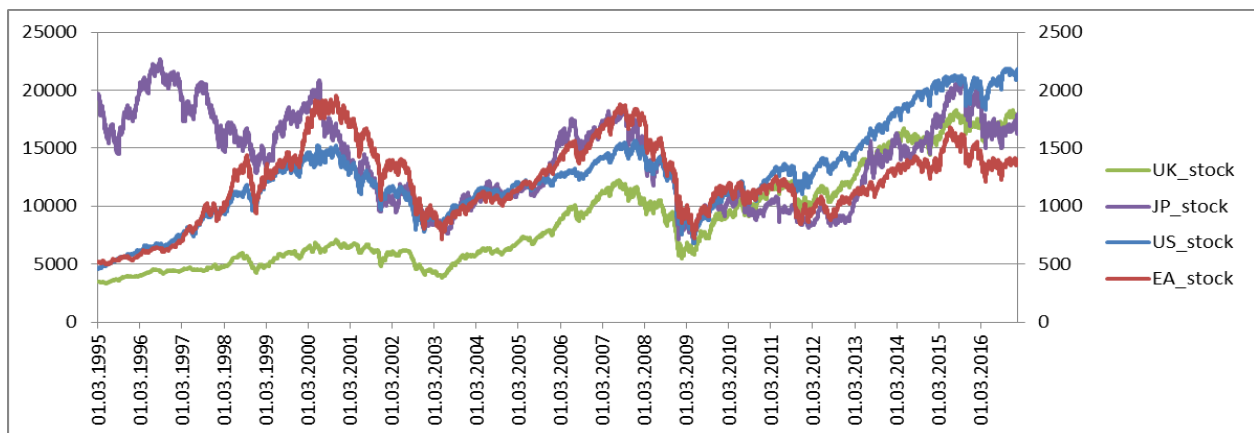


Figure 2. Equity markets for US, EA, UK, and Japan over time



Since we are interested in the short-run dynamics, up to the next four weeks, our estimations were performed in first differences of the bond yields and log price changes of the stocks¹. This usual data transformation also accounts for VAR stability, so that no root lies outside the unit circle.

3.2 Estimation approach

In order to estimate the spillovers we follow the empirical approach proposed by Diebold and Yilmaz (2009, 2012) which is based on VAR variance decompositions.

Firstly, we estimate the VAR(p) model:

$$x_t = \sum_{i=1}^p \Phi_i x_{t-i} + \varepsilon_t, \quad (1)$$

where $\varepsilon \in (0, \Sigma)$ is the i.i.d. errors vector.

A VAR-framework allows us to consider all variables as endogenous, which allows considering non-trivial interlinkages within and between asset markets in advanced economies in a proper way.

The moving-average representation, thus, can be written as

$$x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}, \quad (2)$$

where $A_i = \sum_{k=1}^p \Phi_k A_{i-k}$, A_0 is the identity matrix $I_{N \times N}$ and $A_i = 0$ for $i < 0$.

Our further analysis relies on variance decompositions which allow assessing the fraction of the H-step-ahead error variance in forecasting x_i that is due to shocks to x_j . In order to deal with contemporaneous correlations of VAR shocks, we use the generalized VAR framework, which produces variance decompositions invariant to ordering choice. The generalized approach allows correlated shocks, taking into account the historically observed distribution of errors. Thus, although the method does not identify the causality of spillovers, it relies on historical patterns to identify directionality.

¹ Oil prices, VIX and MSCI Emerging market indices were taken in the model as log differences.

The H-step-ahead forecast error variance decomposition² is calculated as

$$\theta_{ij}^g(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)}, \quad (3)$$

where Σ is the variance matrix for the errors ε , σ_{ii} is the standard deviation of the error term for the i-th equation of VAR and e_i is a vector which contains one as i-th element and zeros otherwise.

The *Total Spillover Index (TSI)* is then constructed as:

$$TSI(H) = \frac{\sum_{i,j=1}^N \widetilde{\theta}_{ij}^g(H)}{\sum_{i,j=1}^N \widetilde{\theta}_{ij}^g(H)} \times 100, \quad (4)$$

where $\widetilde{\theta}_{ij}^g(H)$ is normalized value for $\theta_{ij}^g(H)$, so that $\widetilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)}$. The total spillover index, thus, measures the contribution of spillovers of shocks across variables under consideration to the total forecast error variance.

In order to investigate the direction of spillovers, i.e. the portion of total spillover index that comes from x_i to x_j , the *Directional Spillover Index (DSI)* is applied:

$$DSI_{i \rightarrow j}(H) = \frac{\widetilde{\theta}_{ji}^g(H)}{\sum_{i,k=1}^N \widetilde{\theta}_{ik}^g(H)} \times 100. \quad (5)$$

The last spillover measure of interest is the *Net Pairwise Spillover Index (NPSI)* between variables x_i and x_j which is defined as the difference between gross shocks transmitted from x_i to x_j and gross shocks transmitted from x_j to x_i :

$$NPSI_{ij}(H) = \left(\frac{\widetilde{\theta}_{ji}^g(H)}{\sum_{i,k=1}^N \widetilde{\theta}_{ik}^g(H)} - \frac{\widetilde{\theta}_{ij}^g(H)}{\sum_{j,k=1}^N \widetilde{\theta}_{jk}^g(H)} \right) \times 100. \quad (6)$$

² We consider 4 weeks ahead forecast error decompositions.

The chosen approach allows us to investigate changing-over-time dynamics of spillovers in the form of rolling regressions, and thus, the time variations of total, directional and net pairwise spillovers during the period of observation.

4. Empirical results

4.1 Spillover pattern

Table 1 shows the estimated contemporaneous spillovers between and across systemic bond and equity markets, as well as included control variables.

The matrix is constructed such that each ij -entry (where $i \neq j$) represents the spillover from j -variable to i -variable, whereas each diagonal element stands for own contribution part. Hence, just to convey an example, the first row of the Table 1 considers the US government bond yields, for which the own contribution is equal to 51.98 percent, the spillovers from US stock market is 4.46 percent, the spillovers from Euro area bond and stock markets are equal to 14.14 and 4.42 percent respectively, etc. The first row's last entry shows the sum of the spillovers, which US bond market receive from all other variables – 48 percent. In the second last row we see the spillovers from the variable listed as the column name to all other variables taken together, whereas in the last row add to the previous row the own contribution. Hence, the spillovers from US bond market are equal to 52.4 percent, whereas the sum of US bond market's own contribution and spillovers to others is 104.4. The total spillover index for all included variables across the whole sample period is then calculated according to the equation (4) and is equal to 50.7 percent.

Table 1. Spillovers in bond and equity markets

	US_10y	US_stock	EA_10y	EA_stock	UK_10y	UK_stock	JP_10y	JP_stock	VIX	MSCI_EM	OIL	From Others
US_10y	51.98	4.46	14.14	4.42	14.07	3.62	0.39	0.55	2.71	2.75	0.91	48
US_stock	3.17	37.54	1.57	14.39	1.18	9.5	0.11	1.02	20.64	9.72	1.15	62.5
EA_10y	15.15	2.08	48.7	3.96	21.66	3.41	0.45	0.55	1.52	2.06	0.46	51.3
EA_stock	3.1	15.67	2.69	33.32	2.36	18.72	0.12	1.91	10.29	10.76	1.07	66.7
UK_10y	15.07	1.68	21.88	3.57	50.09	3.18	0.31	0.56	1.19	2.06	0.42	49.9
UK_stock	2.83	13.26	2.43	19.37	2.17	33.75	0.16	2.18	9.99	12.55	1.32	66.2
JP_10y	4.61	1.09	2.68	1.11	2.26	0.94	82.11	3.19	0.82	1.14	0.05	17.9
JP_stock	2.25	12.34	1.49	9.63	1.29	8.09	1.72	44.61	7.97	9.92	0.68	55.4
VIX	2.5	21.36	1.7	11.35	1.21	8.63	0.05	0.95	42.97	8.45	0.84	57
MSCI_EM	2.28	15.1	1.61	12.79	1.45	13.44	0.3	4.98	10.38	35.63	2.04	64.4
OIL	1.41	2.65	0.7	2.68	0.68	3.18	0.1	0.51	1.88	4.27	81.92	18.1
<i>Contribution to others</i>	52.4	89.7	50.9	83.3	48.3	72.7	3.7	16.4	67.4	63.7	8.9	557.4
<i>Contribution including own</i>	104.4	127.2	99.6	116.6	98.4	106.5	85.8	61	110.3	99.3	90.9	50.70%

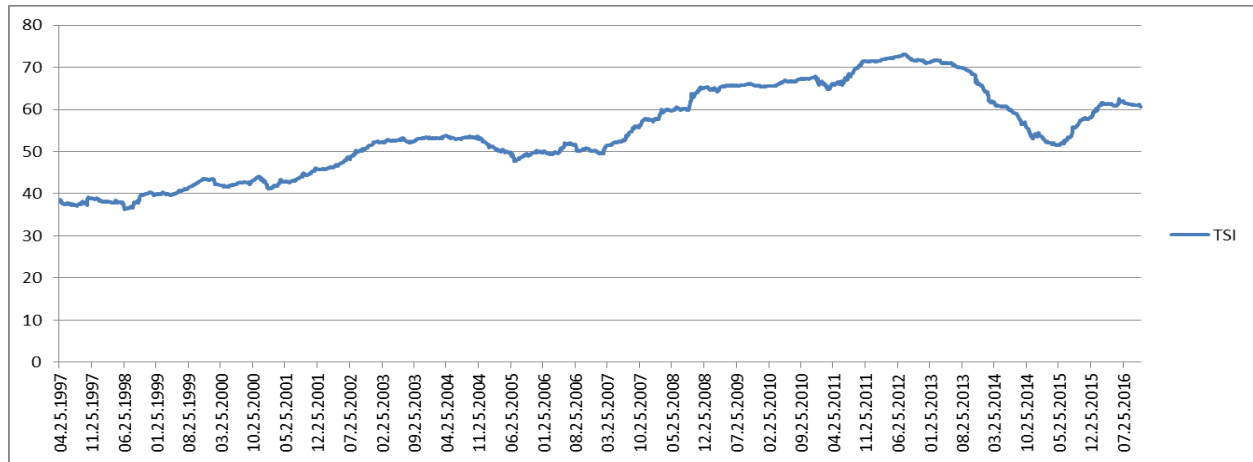
The results emphasize the importance of international spillovers within the same asset classes. However, there are still substantial domestic and international cross-market interlinkages. The US and two European bond and equity markets are found to be highly integrated, whereas the Japanese markets are to a great extent decoupled – firstly, they are less exposed to spillovers from outside, and secondly, contribute only negligible amount of spillovers to others. The latter finding is clearly in line with Beirne and Gieck (2014). The stock market in Japan is substantially more prone to the spillovers from outside than its bond market. Moreover, for both asset classes in Japan we observe that the role of the US is prevailing. Considering two European markets, there appears to be notable two-way spillovers across the Euro Area and the UK, the interconnectedness indices within their equity and bond markets even exceed those with US. In contrast to Ehrmann (2011) and Beirne and Gieck (2014), however, inward spillovers to the U.S. from elsewhere are found to be considerable. The difference might be attributed to another empirical approach, inclusion of the relevant control variables, as well as recent more complex financial structure captured by extending the sample until 2016. The results for the control variables of global risk aversion and developments in emerging markets underline their role as both spillovers' contributors and recipients, whereas the spillovers associated with oil prices are very modest, with the directionality running presumably from stock markets. We now turn to our dynamic analysis of the spillovers, i.e. their change over time.

4.2 Dynamic Analysis

Over the last twenty years covered by the dataset, global economic and political events occurred that are likely to have led to significant fluctuations in the spillovers across markets – the introduction of the Euro, the 2007-09 global financial crisis, the Euro crisis, the implementation of unconventional monetary policies in major advanced countries are a few examples. In the following we will thus perform a dynamic analysis of spillovers in order to monitor the changes in global financial integration.

Figure 3 below shows the estimated dynamics of total spillover index. There is a general upward trend in spillovers – bond and stock markets became more integrated both within and across countries. They became more intense in the periods 2007-2009 and 2011-2013, i.e. in the times of the global financial crisis and Euro crisis which is essentially an important finding of our analysis. After 2013 we observe two striking developments – initially the spillovers have gradually diminished, but then, since 2015, our estimated spillover index is again on an upward trend. The first finding is in line with Raddant and Kenett (2016), who also found that by 2012 the interconnectedness in global stocks shows an empirical co-movement pattern which is very similar to pre-2008 levels. The recent amplification of spillovers detected by us appears to be related to the divergence of the monetary policy stances in the US versus other economies such as the Euro area, and, in this vein, represents a pattern which is clearly corroborating the views of Buitron and Vesperoni (2015), Horvath (2016), IMF (2014) and Bernoth and Koenig (2016).

Figure 3. Total Spillover Index over time



In the following, we continue with our country-wise analysis. In this context, the Figures 4 to 7 show the stability of directional spillovers stemming from each country's both within and across bond and equity markets. Some striking common patterns are observable for spillovers stemming from the US, the Euro area and the UK.

Firstly, spillovers across different asset classes exhibit significant time variations, in relative terms even larger than changes in spillovers within the same asset classes. Thus, we can conclude that the dynamics of total spillover index, presented in Figure 3, is driven by interlinkages both between and within bond and equity markets.

Secondly, there is a common pattern of the spillovers from the US, the Euro area and UK bonds to each of the other country's stock market (see the panel of upper right graphs of Figures 4 to 6). With respect to the spillovers from the US, the Euro area and UK stocks to the other country's bond markets (the panel of lower left graphs of Figures 4-6), we also observe those similarities for all countries, except Japan, for which the pattern differs before 2007-2008.

According to our estimations, the spillovers from the US stock market to the European stock markets were relatively stable starting in 2006, whereas spillovers to Japanese stock markets show an upward trend over the whole time period (lower right graph of Figure 4). Another overall picture emerges for the upper left graph of Figure 4: the spillovers from US bond market to European bond markets were steadily increasing from 2001 to 2007. However, during the acute phase of the GFC the spillovers decreased substantially and recently, beginning in 2014,

increased again. Japanese bond markets started to be prone to the increasing US, Euro area and UK bond markets spillovers not earlier than in 2004. The spillovers from the Euro area bond markets to the respective US and UK markets clearly intensified in the first years after the introduction of the Euro, but have decreased with the outbreak of GFC (upper left graph of Figure 5). Interestingly, we observe overall upward trend for the spillovers from UK stock market to other countries' stock markets over time (lower right graph of Figure 6).

As we have already mentioned above, the spillovers originating from Japan are found to be very limited (in accordance with the vast majority of the literature in this field), so that only Japanese stock market spillovers can be said to play at least some role at the global markets. Accordingly, from the lower right graph at Figure 7 we observe that, until 2011, European stock markets were more prone to the spillovers from Japan's stocks than from the US stock market; however, starting in 2011, the spillovers were quite similar for all countries.

Figure 4. Directional Spillovers from US markets over time

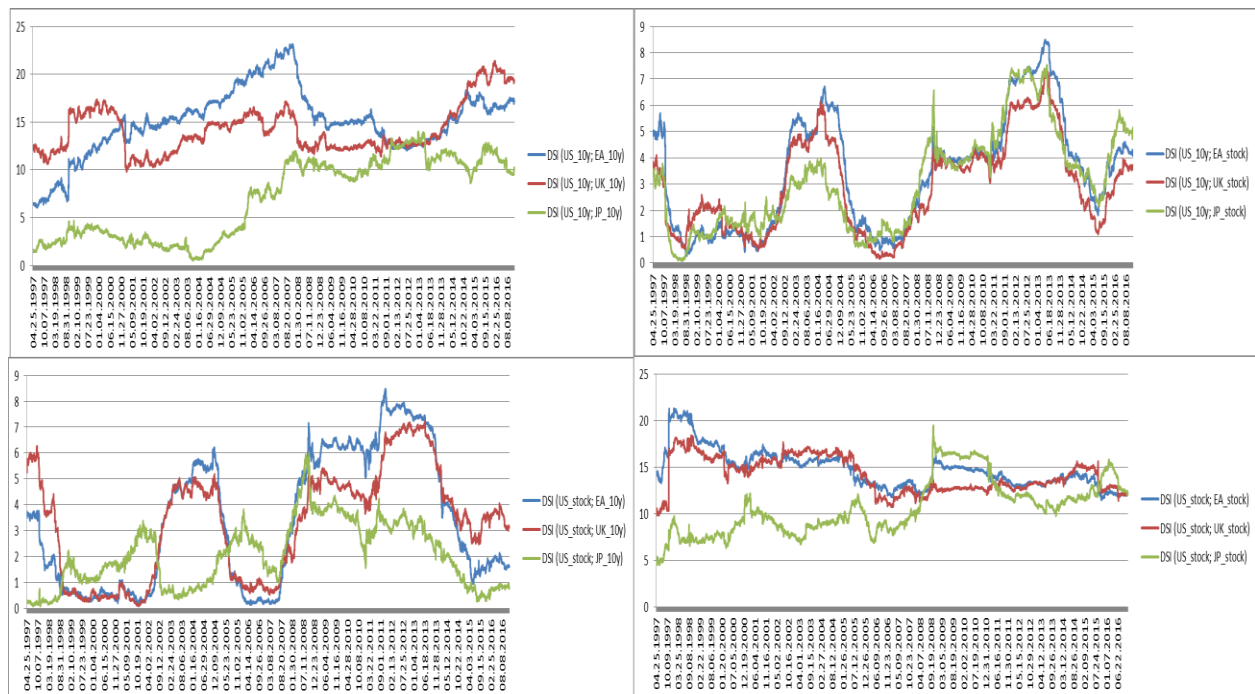


Figure 5. Directional Spillovers from EA markets over time

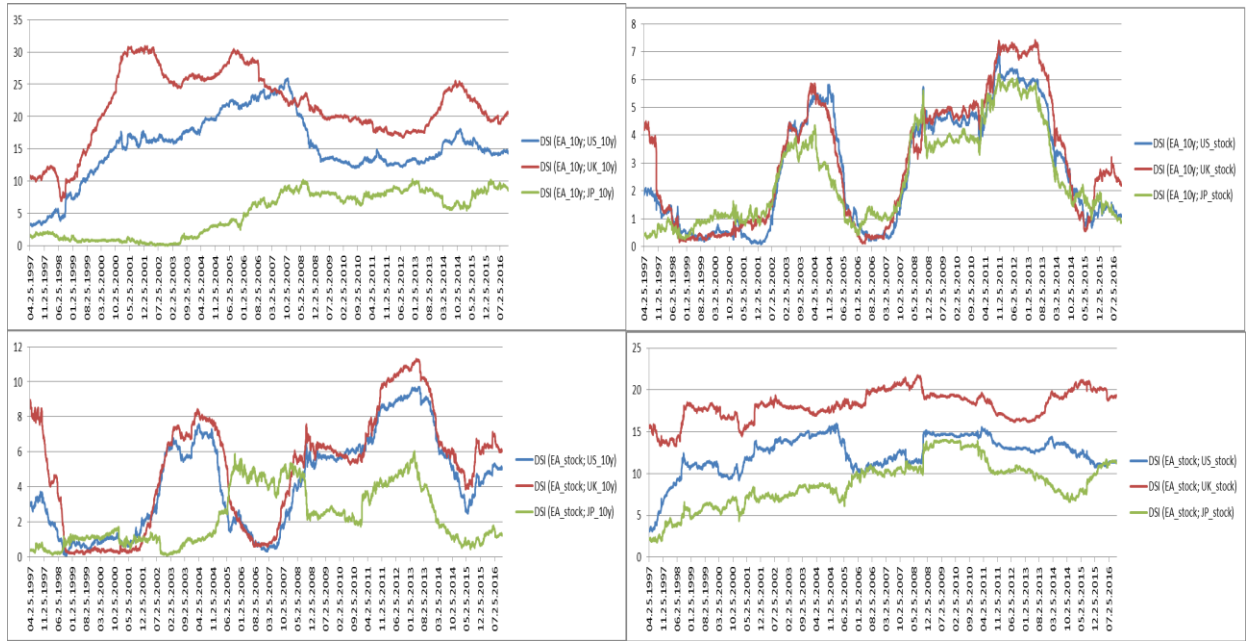


Figure 6. Directional Spillovers from UK markets over time

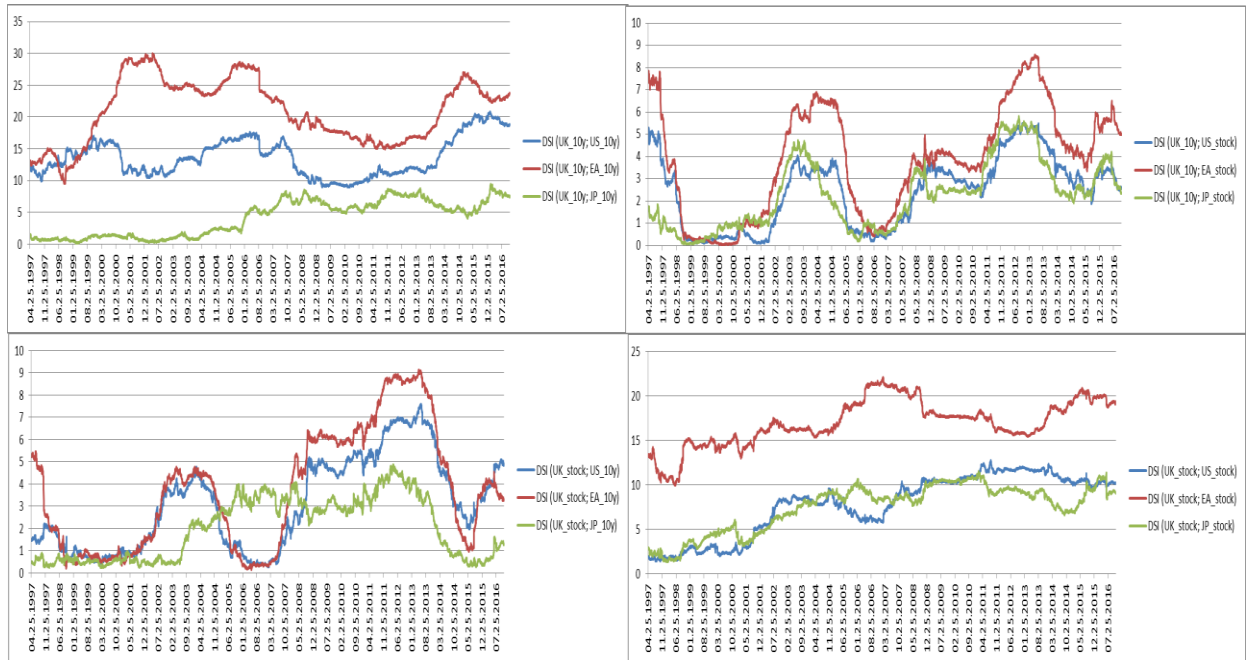
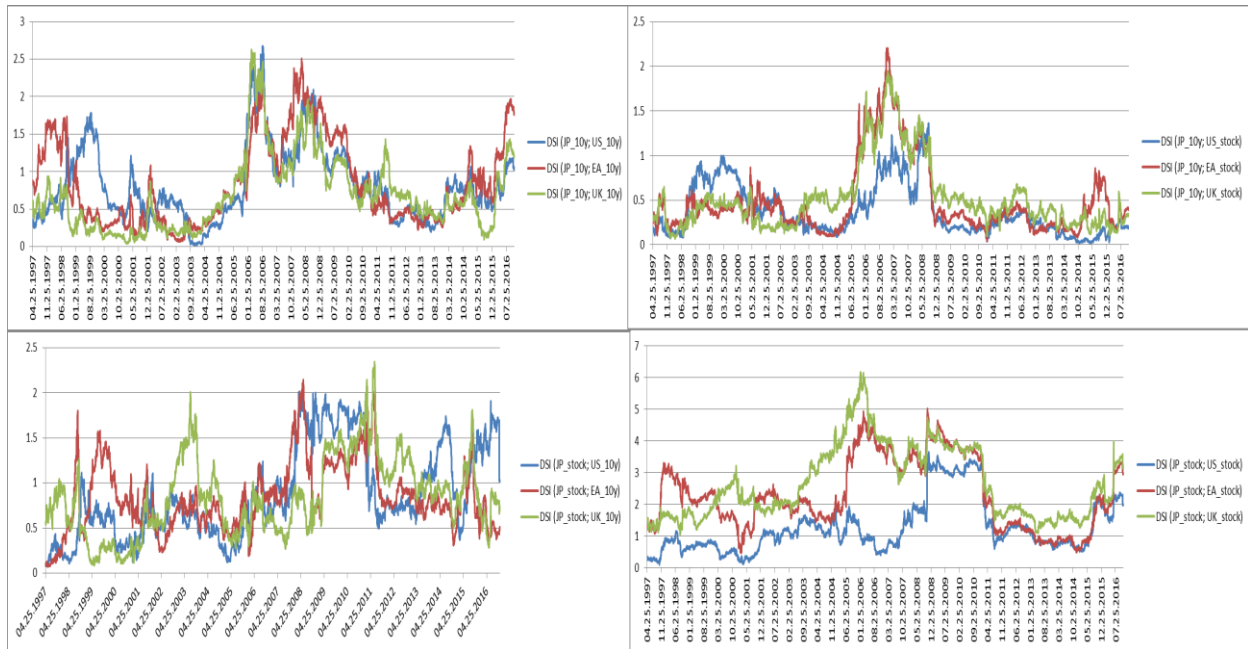


Figure 7. Directional Spillovers from Japanese markets over time



Taken together, we can conclude that the bond and equity markets in the four systemic countries are indeed interconnected in a rather complex way, with the US markets as something like the dominant “gravitation center”. Moreover, the structure of these interconnections shows significant time variations which follow a distinct pattern – a rather innovative result of our study.

5. Robustness checks

We conducted a number of robustness tests in order to check whether our results are sensitive to the model specification and the choice of model parameters³.

In our baseline model presented above we have included international bond and equity variables and analyzed interlinkages between and within countries. One interesting question arises with respect to the role of the money markets and exchange rates for the obtained

³ The robustness tests for different choices of parameters were plausible. The results are available upon request.

relationships. However, the additional inclusion of associated variables in the model poses number of challenges.

Firstly, in the environment in which the policy interest rates are constrained by the zero lower bound and unconventional measures are implemented by the major central banks, the levels and changes of policy interest rates or short-maturity interest rates do no longer provide a complete and coherent measure of monetary policy and its shocks (Claus et al., 2016). From an econometric point of view, the inclusion of the levels and/or changes of policy interest rates or short-maturity interest rates are also not desirable due to their recently very low variations. The latter could lead to difficulties in the interpretation of the results. In order to tackle, at least partially, these issues we have applied shadow short-term rates (SSRs) for the US, the Eurozone, the UK and Japan, which are produced from the research of Leo Krippner and can be downloaded from the Reserve Bank of New Zealand website⁴. The SSRs have become a popular and intuitive indicator of the stance of monetary policy across conventional and unconventional environment (see e.g. Krippner, 2013; Wu and Xia, 2016). Shadow rates are usually equal to the policy interest rate in non-lower bound/conventional monetary policy environments, but can freely evolve to negative values in lower bound/unconventional monetary policy environments to indicate an overall stance of policy that is more accommodative than a near-zero policy rate alone.

The SSRs used here are estimated from yield curve data, and, thus, naturally by construction, we expect high spillovers among these synthetic measures of monetary policy stance and bond yields. One should also be cautious with the interpretation of the spillovers associated with the money markets, since the negative values of SSRs do not represent interest rates at which economic agents transact in reality. Therefore, the levels and changes in SSRs when they are negative should not necessarily be expected to influence the economy and financial markets in the same way as policy rate levels and changes in conventional policy periods. Despite of the aforementioned reasons we still believe that inclusion of such monetary policy measures is a useful exercise to check the sensitivity of obtained in section 4 spillovers in international bond

⁴ Data is available online at <http://www.rbnz.govt.nz/research-and-publications/research-programme/additional-research/measures-of-the-stance-of-united-states-monetary-policy/comparison-of-international-monetary-policy-measures>.

and equity markets, not least because they are widely used. From the Table 2 we indeed see that the additional inclusion of money markets, represented by shadow short-term interest rates, do not disturb the interrelationships between international bond and equity markets.

Table 2. Model with shadow short-term interest rates

	US_10y	US_stock	EA_10y	EA_stock	UK_10y	UK_stock	JP_10y	JP_stock	VIX	MSCI_EM	OIL	SSR_US	SSR_EA	SSR_UK	SSR_JP	From Others
US_10y	35.39	3.01	9.74	2.99	9.56	2.43	0.26	0.38	1.77	1.9	0.62	21.74	6.91	3.29	0.01	64.6
US_stock	2.99	35.71	1.52	13.65	1.1	8.99	0.11	0.97	19.64	9.26	1.11	2.25	1.87	0.79	0.05	64.3
EA_10y	11.3	1.55	36.05	2.99	16.15	2.57	0.33	0.41	1.15	1.55	0.33	6.66	13.8	5.13	0.02	64
EA_stock	2.91	14.73	2.58	31.33	2.21	17.54	0.11	1.8	9.66	10.08	1.02	2.17	2.51	1.31	0.03	68.7
UK_10y	10.95	1.19	16.06	2.59	36.5	2.32	0.24	0.4	0.84	1.5	0.31	6.47	10.69	9.9	0.04	63.5
UK_stock	2.67	12.56	2.34	18.32	2.07	32.01	0.15	2.07	9.44	11.85	1.25	1.94	2.2	1.1	0.05	68
JP_10y	4.22	1.01	2.49	1.01	2.11	0.86	75.88	2.94	0.73	1.07	0.04	3.43	1.84	0.87	1.49	24.1
JP_stock	2.1	11.82	1.46	9.23	1.24	7.75	1.65	43.05	7.58	9.61	0.67	1.75	1.25	0.65	0.19	56.9
VIX	2.37	20.37	1.61	10.91	1.19	8.31	0.03	0.88	40.72	8.2	0.76	2.24	1.41	0.91	0.1	59.3
MSCI_EM	2.22	14.5	1.56	12.21	1.39	12.81	0.29	4.77	10.02	34.11	1.96	1.59	1.56	0.99	0.01	65.9
OIL	1.39	2.61	0.68	2.67	0.69	3.15	0.1	0.5	1.82	4.24	80.37	0.46	0.93	0.35	0.03	19.6
SSR_US	22.63	2.18	6.62	2.33	6.52	1.85	0.23	0.3	1.76	1.35	0.2	41.71	6.87	5.42	0.02	58.3
SSR_EA	8.67	2.21	12.37	2.46	9.68	2.48	0.27	0.27	1.05	1.74	0.5	8.46	41.48	8.31	0.06	58.5
SSR_UK	6.28	1.93	6.29	2.33	11.46	1.75	0.13	0.3	1.13	1.74	0.42	8.81	10.01	47.24	0.18	52.8
SSR_JP	0.69	0.35	0.45	0.29	0.69	0.27	4.83	0.35	0.34	0.16	0.03	1.66	2.25	1.06	86.57	13.4
<i>Contribution to others</i>	81.4	90	65.8	84	66.1	73.1	8.7	16.4	66.9	64.2	9.2	69.6	64.1	40.1	2.3	801.9
<i>Contribution including own</i>	116.8	125.7	101.8	115.3	102.6	105.1	84.6	59.4	107.7	98.4	89.6	111.4	105.6	87.3	88.8	53.50%

The second issue arises with respect to the controlling for the developments in foreign exchange markets. The inclusion of bilateral exchange rates as it was done for example by Ehrmann et al. (2011) in their two-country model, does not seem to be an appropriate choice for our multi-country framework. We have decided to include the nominal effective exchange rates (NEERs) for all countries under consideration in order to control the developments in the foreign exchange markets. Although the interpretation of the spillovers associated with the NEERs is not an easy task, it is still worth to check whether the inclusion of exchange rate measures distort obtained in section 4 interlinkages between bond and equity markets within and between countries. Table 3 present our spillover results for the extended by NEERs model, which are shown to be not sensitive to the inclusion of exchange rate measures.

Table 3. Model with nominal effective exchange rates

	US_10y	US_stock	EA_10y	EA_stock	UK_10y	UK_stock	JP_10y	JP_stock	VIX	MSCI_EM	OIL	NEER_US	NEER_EA	NEER_UK	NEER_JP	From Others
US_10y	50.52	4.38	13.77	4.29	13.65	3.5	0.38	0.58	2.66	2.69	0.88	0.11	0.39	0.17	2.04	49.5
US_stock	3.08	36.16	1.53	13.93	1.16	9.24	0.11	0.97	19.89	9.34	1.11	1.18	0.15	0.17	1.97	63.8
EA_10y	14.89	2.06	47.76	3.92	21.24	3.33	0.45	0.58	1.49	1.96	0.47	0.33	0.08	0.06	1.39	52.2
EA_stock	2.95	14.93	2.58	31.63	2.23	17.81	0.11	1.84	9.79	10.32	1.03	1.09	0.76	0.16	2.78	68.4
UK_10y	14.7	1.66	21.36	3.47	48.9	3.09	0.31	0.59	1.16	1.98	0.43	0.28	0.1	0.56	1.4	51.1
UK_stock	2.66	12.61	2.29	18.37	2.04	31.95	0.15	2.14	9.46	11.99	1.26	2.1	0.11	0.1	2.77	68.1
JP_10y	4.63	1.11	2.72	1.09	2.27	0.96	81.42	3.15	0.84	1.19	0.05	0.04	0.2	0.04	0.29	18.6
JP_stock	2.22	11.74	1.47	9.25	1.3	7.86	1.62	42.34	7.6	9.61	0.64	0.68	0.18	0.17	3.3	57.7
VIX	2.42	20.39	1.6	10.92	1.14	8.37	0.05	0.91	41.23	8.13	0.81	1.22	0.44	0.01	2.36	58.8
MSCI_EM	2.1	13.72	1.43	11.78	1.31	12.39	0.29	4.65	9.4	32.45	1.89	6.44	0.01	0.06	2.09	67.5
OIL	1.33	2.49	0.69	2.55	0.66	3.05	0.1	0.48	1.8	4.09	77.28	4.1	0.2	0.19	1	22.7
NEER_US	0.17	3.5	0.36	2.17	0.33	3.69	0.04	0.63	1.99	10.79	3.13	55.59	15.94	0.1	1.55	44.4
NEER_EA	0.75	0.27	0.07	1.71	0.15	0.26	0.17	0.23	0.53	0.05	0.16	20.68	71.17	3.5	0.31	28.8
NEER_UK	0.3	0.48	0.11	0.48	1.2	0.24	0.15	0.33	0.31	0.28	0.24	0.15	4.34	89.44	1.97	10.6
NEER_JP	3.31	4.27	1.87	5.63	1.88	5.46	0.03	2.28	3.6	4.25	0.83	1.82	0.16	1.37	63.25	36.7
Contribution to others	55.5	93.6	51.9	89.6	50.6	79.2	3.9	19.3	70.5	76.7	12.9	40.2	23.1	6.7	25.2	698.9
Contribution including own	106	129.8	99.6	121.2	99.5	111.2	85.4	61.7	111.8	109.1	90.2	95.8	94.2	96.1	88.5	46.60%

6. Conclusions

In this paper we have estimated the financial transmission between bond and equity markets within and between across the four largest global financial markets. Understanding the complexity of the financial transmission process across various assets required the simultaneous modeling of the various transmission channels in a single, comprehensive empirical framework. For this purpose, we applied identification through generalized forecast error variance decompositions to estimate spillovers across four systemic markets in industrialized countries within a vector autoregression framework. We find that asset prices react strongest to international shocks within the same asset class, but there are also substantial international spillovers across asset classes. The United States turn out to be dominant in a sense that, *ceteris paribus*, spillovers from the US are larger than spillovers received from outside. In that way, we corroborate the findings of the leading research. Our rolling estimations analysis provides evidence that global asset markets have become more integrated over time and, as a somewhat innovative result, that the interlinkages do not stay constant over time.

The interesting finding is that, despite we do not see systematically larger spillovers after the GFC or the European debt crisis *within* the same asset classes, we do observe the increase of

spillovers *across* bond and stock markets in the US, the Euro area and the UK from the end of 2007 to the beginning of 2014. This pattern has not been found as clearly in the previous literature and will certainly be part of future research, in terms of identifying economic or political reasons behind this striking pattern.

Moreover, our results were robust to the inclusion of monetary policy stance measures, as well as to the incorporation of the foreign exchange markets.

In terms of policy conclusions, our estimates at least give some hints at potential contagion channels and, hence, transmission of financial instability. They thus have a bearing on the construction of financial stability safety nets which take account international spillovers. If, for instance, central banks are constrained in their ability to control domestic long-term interest rates, the whole arsenal of macro-prudential policies may to be used to try to control domestic credit creation and safeguard long-term financial stability. In that context, Bernoth et al. (2016) note quite adequately: “US monetary policy may be a key determinant of the global financial cycle (the co-movement of asset prices, credit creation and cross-border capital flows). As US banks hold a sizeable portion of cross-border claims against the Euro area, a tighter US monetary policy may induce a retrenchment in cross-border funding. This may counteract the ECB’s efforts to sustain ample funding conditions in Euro area economies”.

However, we do not at all think that our results per se can be used as arguments in favor of more (monetary, financial etc.) policy coordination. It is true that economic theory suggests that the justification for policy coordination is heavily linked to the existence of cross-border spillover effects. And the strength of such cross-border effects depends on the amount of economic ties, linkages, and the institutional framework – an important relation which is open to further research.

So what are the factors amplifying or mitigating financial spillovers? Various conditions influence the propagation of national shocks which can either intensify or diminish spillover effects. Apparently a high degree of trade openness might further increase cross-border effects. Nominal and real rigidities also affect the amplitude and persistence of spillover effects, as well as the adjustment to shocks. The extent of financial cross-border effects depends on a large variety of factors, such as "the degree of international portfolio diversification, the degree of

prevailing risk aversion, the size and activity of multinational banks, access to funding, the degree of financial market integration and the nature of financial market regulations” (European Commission, 2014). Furthermore, the governance structure, fiscal and monetary policy regime (continuity, in particular, the existence or absence of supranational risk sharing mechanisms) are shown to play a crucial role. Even distance and common language are sometimes mentioned in this regard (Belke and Osowski, 2016).

But it is the existence of large externalities which in addition have to be identified as non-pecuniary which in theory may provide a rationale for any coordination. A necessary but not at all sufficient condition for the latter anyway is a thorough quantification of spillovers as conducted in our paper.

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