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Effectiveness of policy and regulation in European sovereign credit risk markets: a network analysis

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Abstract

We study the impact of changes in regulations and policy interventions on systemic risk among European sovereign entities measured as volatility spillovers in respective credit risk markets. Our unique intraday CDS dataset allows for precise measurement of the effectiveness of these events in a network setting. In particular, it allows discerning interventions which entail significant changes in network cross-effects with appropriate bootstrap confidence intervals. We show that it was mainly regulatory changes with the ban of trading naked sovereign CDS in 2012 as well as the new ISDA regulations in 2014 which were most effective in reducing systemic risk. In comparison, we find that the effect of policy interventions was minor and generally not sustainable. In particular, they only had a significant impact when implemented for the first time and when targeting more than one country. For the volatility spillover channels, we generally find balanced networks with no fragmentation over time.

JEL codes: G20, G01, G17, C32, C55, G28
Keywords: Financial Crises, Policy and Regulation, Financial Stability and Systemic Risk in the Eurozone, High-frequency CDS, bootstrap spillover-measures

1 Introduction

There is large empirical evidence that markets have calmed down after the recent EU sovereign crisis. However, it remains still unclear if and to what extent it is policy interventions or rather regulatory changes which have impacted and mitigated contagion and associated systemic risk most significantly. A thorough understanding is crucial for judging the current and long run implications for the resilience of the system.

In this paper, we analyze the real-time dynamic effects of policy and regulatory interventions on contagion measured as substantial increases in sovereign interdependencies from idiosyncratic shocks (Dornbusch et al., 2000; Forbes and Rigobon, 2002) where specific events have large scale effects on financial stability (Constâncio, 2012). In particular, we use high-frequency data to quantify levels and uncertainty of spillover effects as main drivers of contagion (see Allen and Gale, 2000). Generally, large levels and changes in spillovers mark contagion and instability in the system indicating systemic risk. We provide formal tools in assessing the degree of contagion within a system. Moreover, we can test if changes in size and form of these spillovers over time are significant such that they might cause stabilizing effects of an intervention which we then label as successful in reducing systemic risk. In particular, we introduce an intervention impact measure Δ on the overall system and also more granular on the country level allowing to easily compare different types of actions over time.

We use novel intraday sovereign credit default swap (CDS) data for the years 2009-2014. This time span comprises both, policy interventions and regulatory actions, such as the SMP programs, the ban of trading naked sovereign CDS or the new ISDA rules. We show that with higher than daily observation frequency it is possible to empirically disentangle, record the impact and judge the significance of the different types of events. This complements the many studies on the evolution of systemic risk in the EU sovereign context in the course of policy interventions, which rely only on shorter span daily data before and just shortly after the most important regulatory measures[1]. This limitation of the data prevented investigations on the impact of regulatory changes, and derived point estimates for policy interventions were of unknown precision. In contrast, we provide finite sample adequate bootstrap tools to assess if changes in systemic risk are significant. In order to obtain tight confidence intervals for the impact of closely succeeding events, high-frequency observations are key. In this sense, we contribute to the vast literature on providing point estimates and confidence sets of systemic risk measured as spillover effects in a network set-up (see e.g. Diebold and Yilmaz, 2014; Engle et al., 2014; Hautsch et al., 2015; Betz et al., 2016).

For assessing contagion and thus systemic risk we focus on credit risk spillovers on a high-frequency level. Generally, the joint monetary policy in the Euro area links sovereign credit quality via shared default risk by the temporary European Financial Stability Facility (EFSF) until 2012 and afterwards by the permanent European Stability Mechanism (ESM). Spillovers

[1] Most of the empirical studies in fact only use daily data until 2012/13 (see e.g. Diebold and Yilmaz, 2014; Alter and Beyer, 2014) where the short-selling ban for sovereign CDS was just introduced and the new ISDA rules have not been implemented and/or focus only on ECB policy interventions (see Eser and Schwaab, 2016; Falagiarda and Reitz, 2015; Gibson et al., 2016; Arghyrou and Kontonikas, 2012).

among sovereign bonds occur due to a joint monetary policy transmission mechanism and the collateral framework of the Eurosystem implying cross-effects in CDS. We investigate the short-term aim of policy interventions and regulatory changes to calm financial markets. The short-term effects are also the key for a sustainable rebalancing of the economy in the long run.[2] For stabilization of a country's financial sector, the decrease of volatility in respective yields and spreads is a main concern and therefore an important indicator (see e.g. Gros et al. (2014), Vergote et al. (2017)). With our data, we can thoroughly assess this short-term effect, which in the longer run should then also impact a country's or region's economic outlook and be measurable in key economic indicators such as economic growth, employment rates, fiscal sustainability and financial stability (see e.g. IMF, 2010).[3] Moreover, we can determine if the interventions have reduced the transmission of shocks amongst countries and have therefore also decreased the vulnerability of the financial system as a whole. This clearly is the goal of any macro-prudential policy and requires a network approach.

Technically, we determine interconnections via the order invariant generalized forecast error variance decomposition (see Pesaran and Shin, 1998). We go beyond the status quo of only computing point estimates of unknown precision for this measure (see e.g. Diebold and Yilmaz, 2014) and assess the statistical significance of connectedness by constructing bootstrap confidence intervals. Thus, we can distinguish significant volatility effects from others and thus infer which changes in the measures allow for a meaningful interpretation. In particular, we can apply this to all aggregation levels of the detected spillover network. We can therefore discover significant overall aggregated spillover changes over time but also determine significant spillover channels on the network level at each point in time. This approach enables us to comprehensively evaluate and categorize the effectiveness of crisis-related policy measures and regulation in the CDS market. We explicitly show that our empirical results do not depend on a specific choice of the underlying dynamics and are robust with respect to tuning parameter choices such as rolling window length, forecast horizon and lag length. Also, neither the fact that we use variance decomposition for measuring spillovers nor a specific type of decomposition appears to substantially affect our main findings (see A.Chan-Lau, 2017).

Our novel intraday CDS dataset allows for a better accuracy in estimating spillovers and judging the impact of policy and regulation measures on the dynamics of the European sovereign CDS market. Up to our knowledge, this is the first study investigating the significance of connectedness using intraday CDS data. In particular, due to this intraday data set, it is possible to evaluate the connectedness on a high precision level. This is especially important when studying the impact of specific events on reducing systemic risk where spillovers in respective pre- and post-event windows are compared in order to judge the effectiveness of this policy or regulatory event (see also Vergote et al., 2017). For our intraday data, there are sufficiently many observations within estimation windows of only a few trading days in

[2] See e.g. the communication of the ECB on the direct and indirect mechanisms of the asset purchasing programs `https://www.ecb.europa.eu/explainers/tell-me-more/html/app.en.html`.

[3] Note that such data, however, is very limited, as it is generally available only on quarterly frequencies preventing a thorough analysis of the considered regulatory measures at the current point in time.

order to obtain meaningfully precise estimates. Larger windows covering more trading days would inevitably contain effects of other closely succeeding events and dilute the picture.

We investigate the two most important regulatory changes in the EU sovereign CDS market: the ban on trading naked sovereign CDS in 2012 and the new ISDA rules in 2014. Our analysis provides evidence for their success in terms of reducing connectedness and speculation in affected countries. By quantifying volatility spillovers on all network aggregation levels and taking liquidity effects into account, we uncover the size and the channels of the impact of the ban and the new definitions. In particular, we show that there is more than a simple liquidity story behind the success of the ban and the new ISDA regulation and we explicitly exclude other drivers such as general macroeconomic effects and events as well as market volatility.

Moreover, throughout the crisis, we cannot determine any fragmentation within our CDS sovereign spillover networks and thus conclude that there must be multiple sources of contagion. This insight goes beyond previous studies (see e.g. Ehrmann and Fratzscher, 2017) with bond yields which in contrast to CDS have been shown to suffer from many problems in representing credit risk (see Pan and Singleton, 2008; Ang and Longstaff, 2011).

Furthermore, European-wide measures prove to impact connectedness in a more sustainable manner than measures aimed at one particular country. Unconventional policy interventions which aimed at mitigating systemic risk include economic adjustment programs (EAP) (two for Greece, one for Ireland, Portugal and Spain) and the bond purchases as part of the Security Markets Program (SMP) of the ECB, which was succeeded by the outright monetary transactions (OMT) program. The OMT was introduced after Draghi's speech stating the ECB would do 'whatever it takes' to sustain the Euro. Both the SMP and Draghi's speech are examples of events that targeted the entire Euro area. In addition, we provide evidence for diminishing effects in unconventional policy measures leading to a decrease of their effectiveness. An overview and the timeline of the considered unconventional policy actions is contained in Table 4 in Appendix A.1.

Our paper contributes to the recent literature on network spillover measures (e.g. Engle et al., 2014; Diebold and Yilmaz, 2009) pointing out the importance of checking cross-effects for significance. In particular, for the connectedness literature (see e.g. Diebold and Yilmaz, 2014; Alter and Beyer, 2014) we provide a finite sample accurate bootstrap procedure in order to determine the significance of spillover effects and changes in spillovers. Our empirical results confirm that many changes in spillovers were indeed not significant and should therefore be interpreted with care, especially on the granular network level but also when evaluating aggregate network characteristics. We obtain these results despite the use of high-frequency data, which generally allow for a much better estimation precision than studies with only daily observations. The use of daily data is the standard case in the literature (see also e.g. Claeys and Vašíček, 2012, 2014). Moreover, in contrast to Ehrmann and Fratzscher (2017), De Santis and Zimic (2018) and others, we focus on credit default swaps which pick up credit information more accurately and quicker than bonds (Buse and Schienle, 2019) being less affected by funding liquidity and flight-to-safety issues (see Pan and Singleton, 2008; Ang and Longstaff, 2011). These points are key in particular when evaluating the impact of policy or regulatory actions. Although we are the first to use intraday CDS data to study network spillover effects, the advantages of intraday data in general have been pointed out by several papers. Neil and Fillion (1999) have already stressed that high frequency data should be used to assess the impact of interventions. Similarly, Vergote et al. (2017) argue that daily data is not sufficient to study the effectiveness of the SMP. For further discussions see also Gyntelberg et al. (2018).

Moreover, according to our knowledge, this paper is the first to consistently analyze ECB programs, economic adjustment programs, the ban of naked sovereign CDS as well as the ISDA regulations from 2014. In particular, the impact of the ISDA regulation in 2014 is a key point which has not been studied in the literature so far. It turns out to be more important than the previous measures. Compared to the ISDA regulation, the academic discourse on the ban on short-selling of naked sovereign CDS is long and heated with controversial views. In line with Portes (2010) and Kiesel et al. (2015), we find empirical evidence that banning naked sovereign CDS has stabilized markets and reduced speculation. This is in contrast to models by e.g. Oehmke and Zawadowski (2015) that claim a ban on naked CDS can raise borrowing costs and hence potentially reduces liquidity making the ban overall counter-productive. While their model predicts a negative CDS-bond basis, we empirically find this basis to be almost consistently positive. Short-selling bans have also been analyzed for other markets, e.g. Beber and Pagano (2013a) examined stock markets and found reduced liquidity and a slow-down of the price discovery process. However, a direct comparison with our findings is difficult, because bans on stocks were only temporary and limited to certain stocks.

Research on the effectiveness of the ECB's unconventional policy measures mainly focused on the ECB's asset purchasing programs and analyzed bond yield data, see for example Eser and Schwaab (2016), Falagiarda and Reitz (2015) or Gibson et al. (2016). Also Arghyrou and Kontonikas (2012) analyse the Euro area debt crisis using daily bond data focusing on contagion amongst sovereign entities. By analyzing the effects of policies on CDS markets of both asset purchasing programs as well as EAPs, our paper puts effects of these measures in relative context opening up a much broader perspective on each single action.

The paper is organized as follows: Section 2 carefully describes the intraday data. The model and methods are explained in Section 3. Section 4 details the results. Section 5 discusses several robustness checks. Section 6 concludes the paper.

2 Data

We work with intraday sovereign CDS spreads calculated from price quotes of seven European countries from 01/2009 until 12/2014 as provided by CMA (Credit Market Analysis Ltd.) Datavision.[4] The Euro area sovereign CDS markets were thin prior to 2009, which makes any type of intraday analysis before 2009 challenging. We focus on the countries most affected

[4] Since CDS are traded over-the-counter (OTC), we chose CMA data as it continuously gathers information on executable and indicative CDS prices directly from the largest and most active credit investors. After cleaning and checking the individual quotes, CMA applies a time and liquidity weighted aggregation so that each reported bid and offer price is based on the most recent and liquid quotes.

by the European sovereign debt crisis such as Greece (GR), Ireland (IE), Italy (IT), Portugal (PT) and Spain (ES) as well as on France (FR) and Germany (DE) as more stable, quasi risk-free in terms of credit risk.[5] Reliable sovereign CDS data for Greece is only available until June 2011. CDS trading for Greece ceased entirely with the restructuring in early 2012. We use 5 year USD denominated CDS which are the most liquid.[6]

The country-wise time series of sovereign CDS spreads are presented in Figure 1 and detailed summary statistics are provided in Appendix A.2. The evolution of Euro area sovereign CDS spreads clearly shows the severity of the Euro area sovereign debt crisis, as compared to the financial crisis with only a small peak after the Lehman default in 2008. Figure 1 also indicates that the time from 2009 until end of 2014 is indeed the most relevant period for analyzing sovereign spillover risk in the European market.

Most of the activity for European sovereign entities in the CMA database is concentrated between 8:30 and 17:30[7], which is why we restrict our intraday analysis to this period. The available number of indicative tick-by-tick quotes for CDS does not allow higher equidistant data frequency than 30 minutes. Hence, we have 18 data points or time-stamps per day. For the 30 minute-aggregation of intraday data we do not observe microstructure noise or volatility smiles which are typical for high-frequency data.

Despite the 30-minute aggregation frequency, there are some missing values of which, however, most are due to bank holidays. The following treatment of missing values is carried out for a total of 27,180 time stamps between 2009 and 2014, which amounts to approximately 163,080 observations[8]: If, at a given time stamp, four countries or more have missing values, the entire time stamp is removed which amounts to 7.6% of all time stamps. With this procedure we can analyze all countries jointly in a network analysis. After removing these timestamps, the dataset contains 25,107 timestamps and a total of 150,642 observations. The remaining 2,434 missing observations in the CDS dataset are interpolated via Kalman smoothing.[9] We also deal with peculiarities such as an unequal spreading of missing values over time with an unusually small numbers of available observations in 2009 and 2014 in Section 5. We test for unit roots and stationarity using the Augmented Dickey-Fuller (ADF) test, the Phillips-Perron (PP) test and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test (see Appendix A.2). All tests consistently indicate that the system of EU sovereign CDS returns is nonstationary of unit root type.

[5] We verify that our results are not affected by the choice or number of selected countries by repeating the analysis with four additional Euro area members: Austria, Belgium, Finland and the Netherlands. The results are almost identical and are provided in Section 5.

[6] Sovereign CDS contracts are typically denominated in a currency different from the main tender of the deliverable obligations. The main reason for this is that when the sovereign is faced with a credit event, it is assumed that the local currency will come under considerable pressure.

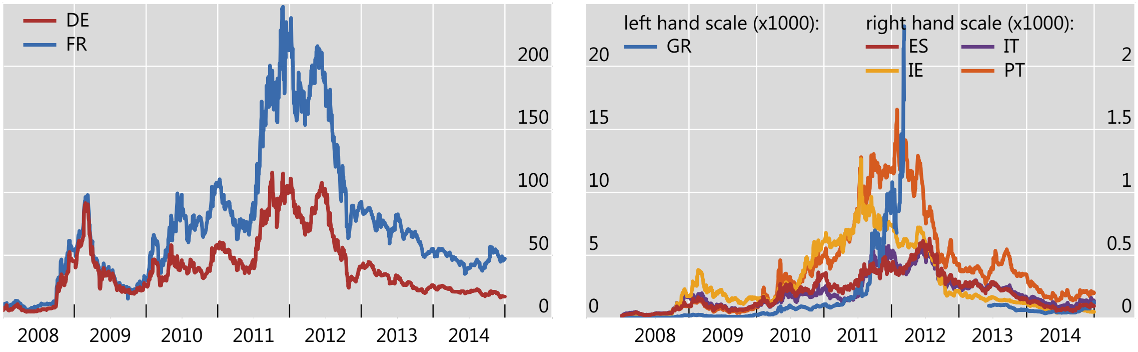
[7] All times quoted refer to Central European Time (CET).

[8] These figures concern the entire dataset from 2009 until 2014 without Greek data.

[9] We have also implemented linear interpolation as a robustness check and find that the two interpolation methods lead to equivalent results.

Figure 1: CDS levels

The figure illustrates the time evolution of CDS spreads based on intraday data. The data is plotted from 2008 onwards to show the impact of the collapse of Lehman Brothers compared to the sovereign debt crisis.



3 Model

In the following subsections we specify the model and terminology. Further we detail also how the significance and precision of the network spillover measures are computed via bootstrapping.

3.1 Dynamic spillover networks

We identify interconnection channels in the EU sovereign credit risk market from time-varying spillover networks of the respective sovereign CDS market. Such dynamic networks are essentially characterized by an adjacency matrix $S = ((s_{ij}))_{ij}$ containing all (undirected) cross-effects in the system $\mathbf{y_t} = (y_t^1, \ldots, y_t^K)$ of all $K = 7$ considered EU sovereign CDS returns. We develop adequate econometric techniques to obtain estimates of S over time as well as to test their significance and the significance of changes over time. Thus for each element s_{ij}, we can characterize the size of the impact and the attached uncertainty of this estimate from country j to i at each point in time.

In particular at each point in time, we derive the directed spill-over effects $\widetilde{s}_{ij}$ as elements of a directed adjacency matrix $\widetilde{S} = ((\widetilde{s}_{ij}))_{ij}$ representing the so-called connectedness of a network (see e.g. Diebold and Yilmaz, 2009). The individual connectedness $\widetilde{s}_{ij}$ is obtained by row normalization in S as the directed relative effect

$$\widetilde{s}_{ij} = \frac{s_{ij}}{\sum_{l=1}^{K} s_{il}}\,, \tag{1}$$

where K represents the number of nodes (countries) in the network. The time index is suppressed for notational convenience. Note that for each country i, the values $\widetilde{s}_{ij}$ mark the percentage share of impact on node i from different sources j. Though cross-effects from a country on the rest of the system in the respective column of $\widetilde{S}$ relate the absolute impact to the different overall aggregated effects on each receiver country. This yields an adequate measure of the severity of the influence. Moreover, we also work with the following two aggregate characteristics of the network: country-wise connectedness and total connectedness. The descriptive weighted out-degree network statistic $\widetilde{s}_j = \sum_{i=1,i\neq j}^{K} \widetilde{s}_{ij}$ aggregates all spillovers from a country j to all others in the system and is denoted by country-wise connectedness. The network density $\widetilde{s} = \frac{1}{K}\sum_{i,j=1,i\neq j}^{K} \widetilde{s}_{ij}$ aggregates all cross-correlation spillover effects in $\widetilde{S}$ and is denoted by total connectedness.[10]

In this paper, we empirically determine the interconnection networks $\widetilde{S}$ over time from the forecast error variance-covariance matrix of a standard dynamic system specification $\mathbf{y_t}$ of CDS returns. This allows for prediction and inference in the resulting spillover measures also during crisis times (Buse and Schienle, 2019), which is key for distinguishing significant from irrelevant effects and changes of effects. Moreover in this way, we can formally evaluate and judge the unconventional policy or regulation interventions identifying systematic changes in size and shape.

In order to get the network spill-over effects over time, we first model $\mathbf{y}_t$ as an appropriate vector autoregression (VAR) for each rolling window sub-period of length T_e as[11]

$$\mathbf{y}_t = \sum_{i=1}^{p} A_i \mathbf{y}_{t-i} + \mathbf{u}_t, \quad t = 1, 2, \ldots, T_e, \tag{2}$$

where A_i are the $(K \times K)$ coefficient matrices and $\mathbf{u}_t$ is an iid white noise innovation with zero mean and variance $E(\mathbf{u}_t\mathbf{u}_t') = \Sigma_u$ with elements σ_{ij} which ensures that OLS-estimates $\hat{A}_i$ of A_i are consistent and efficient in the potentially small estimation window. As our main goal is the analysis of relevant effects of novel policy and regulation measures, the underlying dynamic structure of the system cannot be captured in a static VAR over the entire sample length T. For comparability, we use short subperiods of equal length in which, however, we allow for substantial model flexibility with different VAR specifications. We set the length of the subperiod T_e as short as possible for evaluating the impact of a single action, while still ensuring meaningful point estimates with sufficiently small confidence sets. Therefore, we employ OLS-based MOSUM stability tests (Chu et al., 1995; Kuan and Hornik, 1995) to empirically ensure that estimation sub-intervals are small enough that there are no jumps in parameter values in the VAR in Equation (2). In each sub-period, the respective lag length p in Equation (2) is chosen by the Akaike information criterion (AIC) restricted to a maximum order of three for computational feasibility.[12] Moreover for our event study, the rolling window based approach is superior in econometric accuracy to a general time-varying parameter VAR model for the full sample. Such a model is too slow and less precise in adapting to specific changes capturing these only in a smooth way over time.

The network spillovers are obtained from the underlying dynamic specification by assessing the H-step ahead forecast error variance $FEV(H)$ for any sub-period (Diebold and Yilmaz, 2014). For deriving $FEV(H)$, we require a moving average (MA) representation

[10] Note that the normalisation $1/K$ ensures that the total connectedness and the country-wise connectedness are on the same scale (see Diebold and Yilmaz (2014)).

[11] VAR models have been widely used in the literature to assess contagion (see for example Ahelegbey et al., 2016)

[12] Akaike performs better than Schwarz in small samples (Lütkepohl, 2006).

$\mathbf{y}_t = \sum_{i=0}^{\infty} \Phi_i \mathbf{u}_{t-i}$ of Equation (2) which exists for covariance-stationary returns $\mathbf{y}_t$ (see Appendix A.2 for stationarity and unit-root tests for our data). The $FEV(H)$ is defined as

$$E\Big[\big(\mathbf{y}_{t+H} - \mathbf{y}_t(H)\big)\big(\mathbf{y}_{t+H} - \mathbf{y}_t(H)\big)'\Big] = \sum_{h=0}^{H-1} \big(\Phi_h \Sigma_u \Phi_h'\big), \quad (3)$$

where $\mathbf{y}_t(H) = \sum_{i=H}^{\infty} \Phi_i \mathbf{u}_{t+H-i}$ is the theoretical optimal predictor for known Φ_i. An estimate $\widehat{FEV}(H)$ can be obtained from an estimate $\hat{\Sigma}_u$ of Σ_u by OLS-residuals $\hat{\mathbf{u}}$ of the VAR Equation (2) and standard OLS-estimates $\hat{\Phi}_i$ of the MA-coefficients. In order to obtain a valid connectedness measure, we use the generalized variance decomposition ($GFEVD(H)$) (see Koop et al. (1996), Pesaran and Shin (1998)) of the forecast variance matrix in Equation (3).[13] The decomposition step is necessary in order to identify the specific impact of a shock in one component on the elements of the system (Lütkepohl, 2006). Thus the network adjacency matrix $S(H)$ consists of $GFEVD(H)$ components

$$s_{ij}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' \Phi_h \Sigma_u e_j)^2}{\sum_{h=0}^{H-1} (e_i' \Phi_h \Sigma_u \Phi_h' e_i)} \quad (4)$$

for all $i, j = 1, \ldots, K$, where e_l is a unit vector in T_e, which is 1 in its $l-th$ component and zero otherwise. For a detailed derivation of Equation (4) please see Appendix A.3. From $S(H)$ the directed connectedness network $\widetilde{S(H)}$ and the corresponding aggregate measures can be derived as in Equation (1). For our empirical analysis, we use the estimated version of Equation (4) with $\hat{\Sigma}_u$ and $\hat{\Phi}_i$ and we set $H = 1$, i.e., we compute the $GFEVD$ matrices for one forecast step ahead. This is without loss of generality, since meaningful alternatives with $H = 18$ (one day) and $H = 90$ (one week) forecast steps ahead yield nearly identical results.[14] For notational convenience, we omit the argument of the forecast horizon H in the sequel.

3.2 Significance and precision of network links and changes

We propose techniques to assess the accuracy and significance of network spillover measures and their changes. Our analysis shows that this is important for judging and categorizing the impact of policy or regulatory actions during the crisis where pure point estimates can be misleading. In particular, we propose resampling type procedures for deriving the precision of these measures on all network aggregation levels which are valid even if the amount of available data between successive events is scarce. Hence, we can distinguish significant effects from less relevant spillovers or negligible changes in size or shape when evaluating the impact of crisis events, or policy and regulation measures on connectedness. In other words, we are able to generate a clear ranking of events because we are able to quantify and compare differences in the impact of specific policy actions and regulatory measures.

[13] $GFEVD$ is generally preferred to Cholesky decomposition since it is independent of variable ordering (Koop et al., 1996).

[14] Results are provided upon request.

All our suggested testing techniques for spillover measures based on the network adjacency matrix S from Equation (4) use the following bootstrap procedure. They employ the underlying dynamic VAR-specification in Equation (2) in each estimation window of length T_e. Our bootstrap idea for assessing connectedness measures allows to build confidence intervals from the MA-representation of the underlying VAR(p) (similar to impulse response functions as in Lütkepohl, 2000):

1. Generate $b = 1, \ldots, B = 1000$ series of bootstrap residuals $(\hat{\mathbf{u}}_1^{*,\mathbf{b}}, \ldots, \hat{\mathbf{u}}_{T_e}^{*,\mathbf{b}})$ by resampling with replacement for $t = 1, \ldots, T_e$ from the centered OLS-residuals $\tilde{\mathbf{u}}_t = \hat{\mathbf{u}}_t - \bar{\hat{\mathbf{u}}}_t$, for $t = 1, \ldots, T_e$ of Equation (2).
2. For each $b = 1, \ldots, B$, construct the bootstrapped time series recursively as $\mathbf{y}_t^{*,b} = \sum_{i=0}^{\infty} \hat{\Phi}_i \mathbf{u}_{t-i}^{*,b}$. Obtain bootstrapped estimates $\hat{A}^{*,b}$ and $\hat{\Phi}_h^{*,b}$ using OLS for $\mathbf{y}_t^{*,b}$ in Equation (2).
3. Use $\mathbf{y}_t^{*,b}$ to compute $s_{ij}^{*,b} = \frac{(\sigma_{jj}^{*,b})^{-1} \sum_{h=0}^{H-1} (e_i' \Phi_h^{*,b} \Sigma_u^{*,b} e_j)^2}{\sum_{h=0}^{H-1} (e_i' \Phi_h^{*,b} \Sigma_u^{*,b} \Phi_h^{*,b'} e_i)}$ as in Equation (4). This yields the connectedness measures $\tilde{s}_{ij}^{*,b}$, $\tilde{s}_i^{*,b}$ and $\tilde{s}^{*,b}$ analogous to Equation (1) and thereafter for all $b = 1, \ldots, B$.
4. Define the confidence interval $CI(1-\alpha) = \left[q_{\alpha/2}, q_{1-\alpha/2}\right]$ for each connectedness measure from the quantiles $q_{\alpha/2}$ and $q_{1-\alpha/2}$ of the respective empirical distribution of $\tilde{s}_{ij}^{*,b}$, $\tilde{s}_i^{*,b}$ and $\tilde{s}^{*,b}$ over all $b = 1, \ldots, B$.

When we explicitly report network confidence intervals, we generally set precision bounds with respect to total connectedness. These constitute the statistically adequate finite sample confidence intervals for the overall network density over time and allow to judge overall significant effects of events on total connectedness in the system. Technically, it would also be possible to derive confidence intervals for country-wise or element-wise connectedness within each network at each point in time. But we assess these more granular network measures with respect to a single network-specific accuracy interval.[15] Thus evaluation of relevant network spillovers occurs by a common shared benchmark which is computationally attractive to obtain.

In the following, we assess the significance of relative changes in individual, country-wise and total connectedness by reporting p-values of standard t-tests at each point in time. These are executed by employing the corresponding bootstrapped $(1-p)$-level confidence intervals as described above. Across all considered events of announcement or implementation of policy or regulatory measures, we quantify the implied shift in spillover strength and shape by analyzing periods before and after. Moreover, with a simple difference-in-difference approach we can formally test for the significance of these effects.

Note that for such deeper inferential-type analysis, an underlying dynamic model in each rolling window is crucial. In particular, for purely descriptive spill-over measures as e.g. realized volatilities such conclusions could not be drawn. The specific type of time series models, however, are of minor importance as long as the main parts of the evolution in the mean are captured. Please see Section 5 for details.

[15] Note that by construction, individual connectedness is not necessarily smaller (larger) for the lower (upper) confidence interval boundary from total connectedness.

4 Results

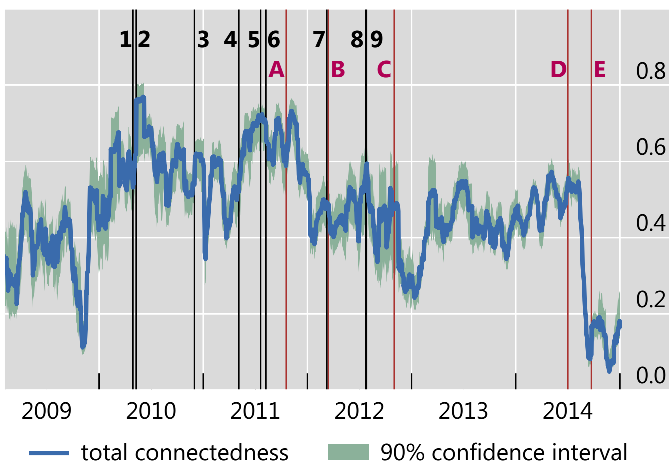
During the European sovereign debt crisis there have been various efforts to stabilize and calm markets. We investigate how these interventions affected connectedness respective systemic risk in credit-risk markets using intraday CDS spreads. In addition, we analyze the spillover channels and investigate the topology of corresponding cross-effect networks. The considered period from 2009 until the end of 2014 contains several important crisis-related policy measures and changes in CDS market regulations depicted in Figure 2. The detailed chronological evolution of events is shown in Appendix A.1. In the following, we discuss the impact of events in thematic subsections structured along the importance of our main empirical findings.

4.1 Empirical setup and overall picture

We focus on size and significance of the impact of the eight key policy actions and two most important regulatory changes on (aggregate) network cross-effects in the EU sovereign credit risk market in the years 2009-2014. Figure 2 provides an overview of the considered actions and reports the total connectedness as an aggregate measure of network spillover density over time with corresponding pointwise confidence regions. A first qualitative graphical comparison of CDS spreads in levels in Figure 1 and the spillovers in Figure 2 reveals a fundamentally different time evolution associated with a drop in CDS spreads after 2012 while contagious spillovers remain persistently high until 2014. The decrease in CDS spreads corresponds to a reduction of speculation.

Figure 2: Time line events and total connectedness

The figure illustrates total connectedness with 90% confidence intervals. Crisis related events are marked as black lines and regulatory interventions are shown by purple lines. The connectedness is computed with a rolling window of 20 trading days taking daily steps for new windows. A fixed number of days implies that when observations are missing, there might be less than 360 observations in one estimation window.



1: Greece: crunch talks	28.04.2010
2: SMP 1st wave	10.05.2010
3: Ireland EAP	30.11.2010
4: Portugal EAP	03.05.2011
5: Greece 2nd EAP	21.07.2011
6: SMP 2nd wave	08.08.2011
7: Greek default	09.03.2012
8: Spanish banks EAP	20.07.2012
9: Draghi's speech	26.07.2012
A: agreement on ban	18.10.2011
B: announcement of ban	14.03.2012
C: implementation of ban	01.11.2012
D: "FAQ" new CDS rules	01.07.2014
E: implementation of rules	22.09.2014

With high-frequency data, we are able to detect and identify the immediate effects of interventions from very short time windows close to the actions where we show that the influence of external market based factors is minor (see Subsection 4.2.2). We determine network spillovers from the $GFEVD$ in Equation (4) of an underlying VAR in the system in Equation (2) in a flexible rolling windows scheme of size $T_e = 90$ corresponding to about five trading days. This allows to separately identify effects of closely consecutive policy events at a reasonable estimation accuracy. For regulatory changes characterized by a more lengthy implementation process, however, we study the cross-effects over a longer time period, setting the rolling window size to 180 observations, i.e. around 10 trading days.[16]

We evaluate the effectiveness of policy interventions by assessing individual connectedness on the network level but also aggregated measures as country-wise and total connectedness in addition to level changes. Note that due to the estimation lag for determining the network spillovers from the $GFEVD$ in Equation (4), pure post-event windows for connectedness measures generally only start 90 observations after the event, or 180 observations for regulatory actions. We take these as the main conservative reference point for determining the effectiveness of an intervention rather than the short-term joint adjustment.[17] As a comparison, we also study event impacts in CDS levels where the evaluation periods start directly after the event. In contrast to the network spillovers, for CDS spreads we do not need to consider a rolling window until the event is fully incorporated.

We formally assess the significance of an intervention starting at an event $I1$ and being implemented at $I2$ (where in some cases we have $I1 = I2$) in reducing spillovers with two-sample t-tests. These tests allow us to check if the mean spillover levels before $I1$ and after $I2$ are identical. Moreover, we measure the intervention impact as $\Delta_{I1,I2}$ marking the relative change $((\overline{I2+}) - (\overline{I1-}))/(\overline{I1-})$ in % where $\overline{I1-}$ is the time mean of connectedness before $I1$ and $\overline{I2+}$ after $I2$. Generally, results are reported for total and country-wise connectedness based on CDS spreads. Note that Δ is comparable across different types of interventions due to the percentage scale. In the case of closely consecutive policy interventions, we additionally conduct Chow-tests for linear structural breaks to capture changes in trending slopes. With high-frequency observations, we measure the real observed impact of an intervention in contrast to a hypothetical impulse response analysis (Alter and Beyer, 2014).

4.2 The impact of regulatory actions

There have been two major regulatory changes in the CDS market during the European sovereign debt crisis. The first is the ban on short-selling uncovered sovereign CDS in 2012

[16] We find that for a grid of window sizes of the rolling bins between 5 days (90 observations) and 40 days (720 observations) with and without Beta-weighting scheme (see Ghysels et al., 2007), the window width only affects the variability but not the overall dynamic structure of the resulting connectedness. Due to missing data 90 (180) time-stamps may correspond to slightly more than five (ten) trading days.

[17] This is in line with the literature which has used at least 3-5 days past event windows to determine medium range sustainable impacts separated from generic short-term strengthening of connectedness due to comovements of markets. The shift is chosen based on the assumption that credit risk markets react fast to news (see e.g. Daniels and Jensen, 2005 and Gyntelberg et al., 2013). We have also repeated the computation with no shift of the evaluation period which yields the same systematic type of results with even stronger quantitative impacts.

and the second is the market-led change to CDS trading resulting in new CDS definitions and standard reference obligations defined by the ISDA in 2014. We show that both regulations were successful in reducing contagion through decreasing overall and country specific levels of spillovers. We can exclude different drivers as an explanation of the success of the regulatory actions.

4.2.1 The large significant impact of the ban and the new ISDA rules

The new ISDA rules on CDS trading in 2014 introduced a multiple of fundamental changes in the trading of CDS. The key points of the new rules were an increase in CDS market transparency, the standardization of the reference obligation triggering a reduction of search costs, a reduction of trade break risk and a consistent treatment of cleared and uncleared transactions. Generally, higher market transparency improves the well-functioning of markets and decreases contagion (Trichet, 2002). In particular, the new standards on governmental interventions for bailout and the so called Asset Package Delivery measure were intended to reduce adverse spillover spirals in governmental credit risk interconnections.

Our analysis is the first to empirically confirm the intended decrease in contagion by detecting a dramatic reduction of overall sovereign spillovers measured in total and country-wise connectedness between the publication of the details of the rules (01.07.2014, marked by D) and their implementation (22.09.2014, marked by E). This is qualitatively illustrated in the upper part of Figure 3. Moreover, we find that the reduction in spillover risk is strongly significant, as can be directly inferred from the confidence intervals of total connectedness in the left-hand panel (a1) of Figure 3. The country-wise connectedness of all countries decreases strongly and almost synchronously (see Figure 3 (a2)), which suggests a systematic decline in spillover risk rather than pure country specific explanations.[18]

We formally test for the effectiveness of the new rules in reducing contagion on all aggregation levels. Moreover, we calculate the intervention impact $\Delta_{D,E}$ in % for the overall spillover changes but also on the country-level. The numbers in Table 1 show the significant decrease in spillovers on all levels with tiny p-values $p_{D,E}$ throughout (see right-hand panel in Table 1). Moreover, the values of $\Delta_{D,E}$ demonstrate a uniformly drastic drop of more than 50% in total spillover risk. Overall, before the implementation of the new ISDA rules, connectedness and associated contagion in all countries returned close to or even exceeded pre-ban values (comparing column $\overline{D-}$ with $\overline{A-}$ in Table 1) and was only substantially and sustainably reduced by the new CDS rules to a total level of 0.18 and below 0.30 in all countries.[19]

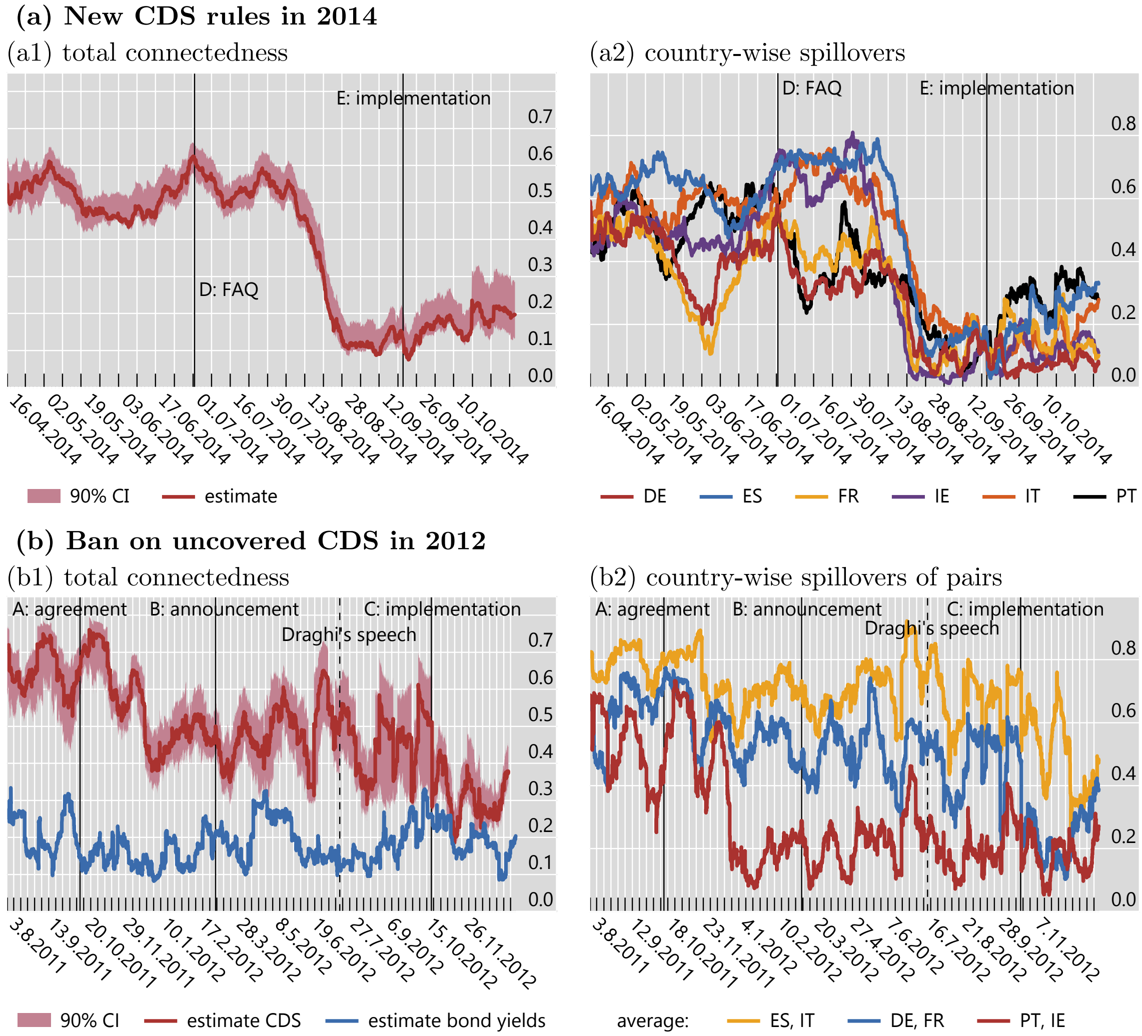
The permanent ban on outright short-selling of sovereign CDS contracts across all members of the European Economic Area (EU regulation 236/2012) was introduced in 2012 due to concerns that speculative behavior in the sovereign CDS market led to excessively high credit spreads in the most distressed countries. It had the clear goal of reducing the risk of price

[18] See e.g. a country-specific action like the Portuguese bail-in for Banco Espirito Santo (03.08.2014) had no visible direct systematic effect at all.

[19] This result is even strengthened when taking post-event windows with no time-shift for estimation directly after each event. We also computed robustness checks which can be found in Table 7.

Figure 3: Total and country-wise spillovers around regulatory interventions

The figure shows the evolution of CDS spread connectedness around the introduction of new CDS rules in 2014 (upper panel (a), starting with event D and implemented at E) and the ban of naked sovereign CDS in 2012 (lower panel (b), starting with event A, implemented at C). The red solid lines in the left-hand figures depict the total amount of spillover effects in the network measured as $\tilde{s}$, calculated from the $GFEVD$ components in Equation (4). The shaded red area presents the 90% pointwise confidence intervals. In the lower panel, also the total connectedness of bond yields is added in blue. Both right-hand figures show country-wise connectedness, where in the lower figure (b2) pairs of countries with similar connectedness time path are aggregated for an augmented graphical exposition. In all cases, a rolling window size of $T_e = 180$ observations is used. The labeling of events is as in Figure 2.



spirals and enhancing the stability of the sovereign debt market.[20] Despite its intended effect on prices, speculation and market confidence, there exists only mixed theoretical guidance on its consequences for spillovers and contagious effects. While speculation generally produces many interlinkages (Jeff Fleming et al., 1998), a short selling ban might as well reduce overall

[20] See MEMO/11/713 of the European Commission Commission (2011).

Table 1: Intervention impact of regulatory measures

For each regulatory intervention I, we evaluate its impact by assessing spillovers before the respective starting action $I1$ and after the final implementation stage $I2$. The table presents time aggregates in mean with respective empirical standard deviations in parentheses of connectedness over a window of 200 observations before an intervention $\overline{I1-}$ or after $\overline{I2+}$. The p-value of the two-sample significance test for a constant spillover level in the time interval of $\overline{I1-}$ and $\overline{I2+}$ is reported as $p_{I1,I2}$. The intervention impact is measured as $\Delta_{I1,I2}$ marking the relative change $((\overline{I2+}) - (\overline{I1-}))/(\overline{I1-})$ in %. Results are reported for total (in bold) and country-wise connectedness based on CDS spreads. In the case of the ban, effects for total connectedness of bond yields are also reported as additional control in the line bonds. The labeling of events is as in Figure 2.

	Ban 2012: events A and C				**New CDS Rules 2014**: events D and E			
	$\overline{A-}$	$\overline{C+}$	$p_{A,C}$	$\Delta_{A,C}$	$\overline{D-}$	$\overline{E+}$	$p_{D,E}$	$\Delta_{D,E}$
total	**0.60(0.03)**	**0.27(0.05)**	**0.00**	**-55.00**	**0.54(0.04)**	**0.18(0.03)**	**0.00**	**-66.67**
DE	0.54(0.06)	0.17(0.06)	0.00	-68.52	0.45(0.04)	0.08(0.02)	0.00	-82.22
ES	0.77(0.05)	0.43(0.08)	0.00	-44.16	0.60(0.06)	0.26(0.04)	0.00	-56.67
FR	0.80(0.02)	0.22(0.04)	0.00	-72.50	0.45(0.07)	0.16(0.05)	0.00	-64.44
IE	0.27(0.05)	0.16(0.07)	0.00	-40.74	0.57(0.09)	0.11(0.03)	0.00	-80.70
IT	0.73(0.03)	0.52(0.08)	0.00	-28.77	0.56(0.03)	0.15(0.04)	0.00	-73.21
PT	0.48(0.04)	0.07(0.04)	0.00	-85.42	0.60(0.04)	0.30(0.05)	0.00	-50.00
bonds	**0.25(0.06)**	**0.20(0.04)**	**0.00**	**-20.00**				

market liquidity, impede price discovery, and increase volatility potentially leading to more spillovers (Boehmer and Wu, 2013; Boehmer et al., 2013; Beber and Pagano, 2013b).

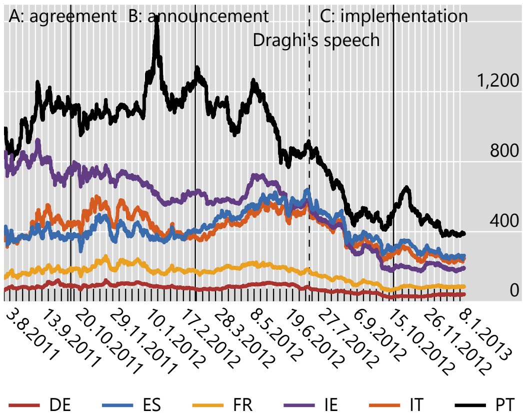
The substantial reduction of CDS spreads in Figure 1 (lower panel) suggests that the ban may have had a strong impact on scaling down speculation. For the new ISDA rules, the reduction in CDS levels was only minor (see Figure 1). During the ban, we find that CDS spreads decreased most for Portugal and Ireland, the countries which were most affected by speculation (see Figure 4).[21] The amount of speculation in the market can be inferred from the table on the right of Figure 4. The table displays the net notional amounts of outstanding CDS contracts divided by the amount of bonds traded on the MTS platform (as a proxy of bond market size) aggregated on annual frequency. We see that up to and including 2012 the CDS market grows faster than the bond market. Most importantly the growth is strongest for Greece, Ireland and Portugal, supporting our notion of strong speculations against these countries in the CDS market. The empirical identification of the intervention impact of the ban in spillovers is complicated by the fact that during the period between the first agreement on the ban (18.10.2011, event A) and its implementation (01.11.2012, event C) further important crisis-related events took place, such as e.g. Draghi's speech. In order to disentangle the effects of the CDS ban from other events we zoom in on different implementation stages of the ban and also compare the connectedness measures of CDS spreads (in red in Figure 3 (b1)) and bond yields[22] (in blue in Figure 3 (b1)). In particular, the fact that the credit situation of a sovereign entity can be inferred from both bonds or CDS,

[21] This is also the case for Greece, however the ISDA triggered a Greek default in 2012 and hence we do not consider Greece from 2012 onward.

[22] We use 5-year zero coupon sovereign intraday bond yields from MTS.

Figure 4: Speculation

The figure on the left illustrates CDS levels around the ban. The table in the right part of the figure presents a proxy for speculation in the sovereign CDS market by depicting annually aggregated net notional amounts of CDS outstanding based on weekly DTCC data divided by aggregated bond trading volumes based on tick-by-tick data from MTS.



	2009	2010	2011	2012	2013	2014
DE	6.8	7.0	10.1	15.1	7.3	8.4
ES	6.0	4.4	7.2	6.9	3.0	1.5
IE	10.7	12.0	44.9	85.4	34.2	5.5
IT	1.1	1.1	1.1	1.4	0.8	0.4
FR	3.1	2.3	3.3	4.6	2.7	2.1
PT	0.0	4.6	20.8	27.2	14.1	1.5
GR	15	13.7	127.3	–	–	–

allows for identification of the impact of the ban since bonds are not directly affected by the CDS regulation. After the initial agreement on a permanent short-selling ban on 18.10.2011 (event A), we observe a significant decrease in CDS connectedness while connectedness based on bond yields remains at a steady level decreasing only from 0.25 to 0.2. Moreover, a detailed look at the different implementation stages of the ban and Draghi's speech in Table 2 suggests that among the two, the ban was the driving force in reducing CDS connectedness. In contrast, the impact of the Draghi speech on the total connectedness was minor. In particular, as total connectedness directly returned to pre-Draghi values before the final implementation of the ban and only the implementation finally reduced it (see lower panel in Figure 3). Concerning speculation, however, the situation is different in CDS levels. Here, the lower panel of Table 2 indicates a stronger impact of Draghi's speech on the reduction of CDS spreads ($\Delta_I = -7.96\%$ compared to $+17.18\%$ for the implementation). This visible decline in CDS levels justifies the often attributed prominent and substantial impact of Draghi's speech in the fight against the Euro area sovereign debt crisis but only for reducing speculation in the markets. For decreasing contagion, however, the ban was key.

Overall for the entire ban period, if we look at per country effects, we find that country-wise connectedness falls most for Portugal and substantially for Ireland (see Table 1 and the right-hand lower part (b2) of Figure 3). A large part of this drop might be attributed to a cease in speculation. In particular, the country-wise connectedness of Italy and Spain remains rather unchanged after the announcement of the ban and both stay at rather high levels with $\overline{C+}$ above 0.4 after the implementation (see Table 1). In contrast, the connectedness of Ireland and Portugal decreases quickly for the period $\overline{C+}$ below 0.2 and also with some time delay, France and Germany experience a significant drop in spillover risk (Figure 3) reaching

Table 2: Disentangling the intervention impact of the ban

For each intervention stage I, we evaluate the impact by assessing total spillovers and averaged CDS spreads before I and with respect to the initial agreement A on the ban (A, I). The setup is as in Table1 using window sizes of 200 observations for time mean aggregates $\overline{I-}$ and $\overline{I+}$. The direct (relative) intervention impact Δ_I ($\Delta_{A,I}$), and the two-sample significance test for constant (spillover) levels in the time interval of $\overline{I-}$($\overline{A-}$) and $\overline{I+}$ is reported as $p_I(p_{A,I})$. The labeling of events is as in Figure 2.

Total connectedness

I	Event	$\overline{I-}$	$\overline{I+}$	p_I	Δ_I	$p_{A,I}$	$\Delta_{A,I}$
A	Agreement	0.60(0.03)	0.72(0.03)	0.00	20.00	–	–
B	Announcement	0.48(0.02)	0.45(0.06)	0.00	-6.25	0.00	-25.00
9	Draghi	0.54(0.06)	0.37(0.04)	0.00	-31.48	0.00	-38.33
C	Implementation	0.53(0.04)	0.27(0.05)	0.00	-49.06	0.00	-55.00

Average CDS levels

I	Event	$\overline{I-}$	$\overline{I+}$	p_I	Δ_I	$p_{A,I}$	$\Delta_{A,I}$
A	Agreement	491.70(23.48)	481.26(25.18)	0.00	-2.12	–	–
B	Announcement	467.85(31.11)	471.80(33.91)	0.22	0.84	0.00	-4.05
9	Draghi	459.28(23.93)	422.72(27.33)	0.00	-7.96	0.00	-14.03
C	Implementation	216.83(16.41)	254.09(20.46)	0.00	17.18	0.00	-48.32

similarly low levels of $\overline{C+}$. Both suggest that speculators left the market as intended by the ban. This behavior is in contrast to the time evolution of country-wise connectedness after the CDS rules in 2014, where the individual connectedness of all entities decreased about equally strong and almost synchronously (Figure 3). The decrease was at a much larger scale with an overall $\Delta_{D,E} = -66.67\%$ (cp. $\Delta_{A,C} = -55.00\%$ for the ban) to much smaller levels $\overline{E+} = 0.18$ compared to $\overline{C+} = 0.27$ after the ban (Table 1). Overall, we rate the ban as successful in reducing spillover risk confirming theoretical model findings by e.g. Che and Sethi (2014); Portes (2010). But in scale and impact the new ISDA rules were more important for a sustainable large-scale decrease of contagion.

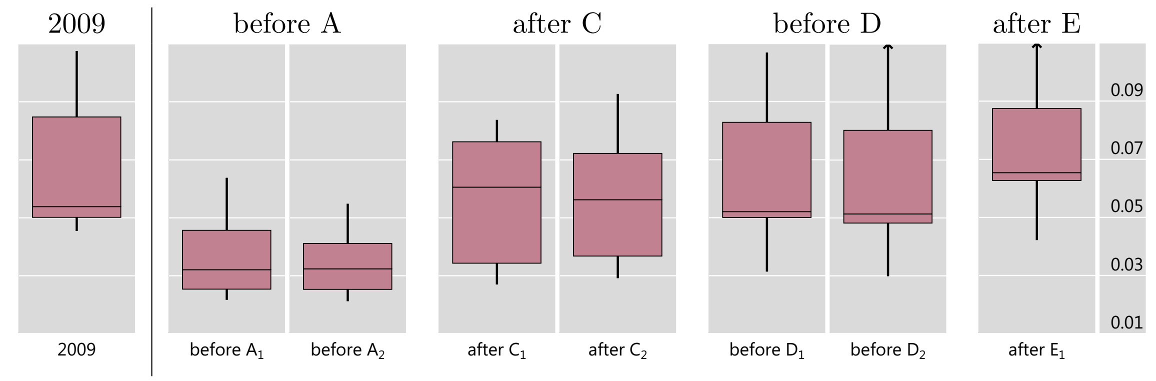
4.2.2 Excluding different drivers of the intervention impact

In the following, we investigate the influence of different potential drivers of the intervention impact. We show that with high-frequency observations our measure Δ accurately quantifies the amount of impact of the intervention. In particular, we detect changes in connectedness in a short-time span directly after an intervention around and during which we show that other factors such as liquidity or common external market factors remain largely stable. Thus, we can attribute observed decreases in contagion around regulatory interventions in Subsection 4.2.1 mainly to the intervention.

Liquidity
Generally, tighter CDS regulations could induce less liquidity in the market yielding also a drop in spill-over effects (see, e.g. Duffie, 2010). In this sense, potentially reduced price informativeness due to a less efficient pricing of credit risk by CDS could also cause a drop in information content about contagion obtained by CDS spillovers (see, e.g. Silva et al., 2016). However, our detected decreased spillovers do not coincide with and are therefore not a consequence of a drop in liquidity (see Figure 5).

Figure 5: Liquidity

The figure illustrates the relative bid-ask spreads as a liquidity proxy defined as (ask price-bid price)/((ask price+bid price)/2) of CDS-spreads around regulatory intervention dates associated with the ban 2012 and the introduction of the new ISDA rules 2014. The benchmark year 2009 before the sovereign crisis is shown for comparison. As in Table 1, boxplots are calculated for time averages in two distinct windows of 200 observations each before and after the event varying in the cross-section of countries. The labeling of events is as in Figure 2.



In fact, we find no evidence for a drying out of the sovereign CDS market due to the ban or the new ISDA definitions. This finding is robust for different measures of liquidity. We illustrate this with boxplots summarizing the relative bid-ask spreads across countries in the pre- and post-periods of both regulatory interventions relative to the pre-crisis benchmark of 2009 in Figure 5.[23] Around the regulatory interventions, relative bid-ask spreads only change moderately as the scale in Figure 5 indicates. In particular, relative to the 2009 situation, during the interventions and well until 2014, liquidity was even higher reaching the pre-sovereign crisis level only in 2014 (see also Figure 14 in Appendix A.4 for the detailed time evolution). We also confirm these findings by two further proxies of liquidity, namely net notional amounts outstanding and number of trade counts (see Figure 15 in Appendix A.4). Hence, the reduction of connectedness around regulatory interventions cannot be explained by a simple liquidity argument.

[23] We take 2009 as benchmark where the introduction of the first clearing houses and the standardization of contracts due to the ISDA "Big Bang Protocol" yielded some minimum standards of transparency and market integration in the European sovereign CDS market. Market activity before is thus not comparable.

Other external factors
Our aim is to understand the impact of Euro area policies and general regulations on Euro area credit spreads and interconnectedness. The Euro area sovereign debt crisis was embedded in a global crisis. Thus, events outside the Euro area as well as changes in the general condition of credit markets and financial markets might have influenced sovereign credit spreads and yields within the Euro area. In the same way, also interventions from within the Euro area might have affected financial markets outside the Euro area. We will, however, show that before and during the detected reactions of Euro area sovereign debt markets in response to a "European" regulation, there are only weak movements in other global sovereign markets, the general financial market and the general credit market situation. Hence, the reaction of the Euro area sovereign debt market is most likely due to that regulation and the strong movements of connectedness and spreads cannot be explained by external factors.

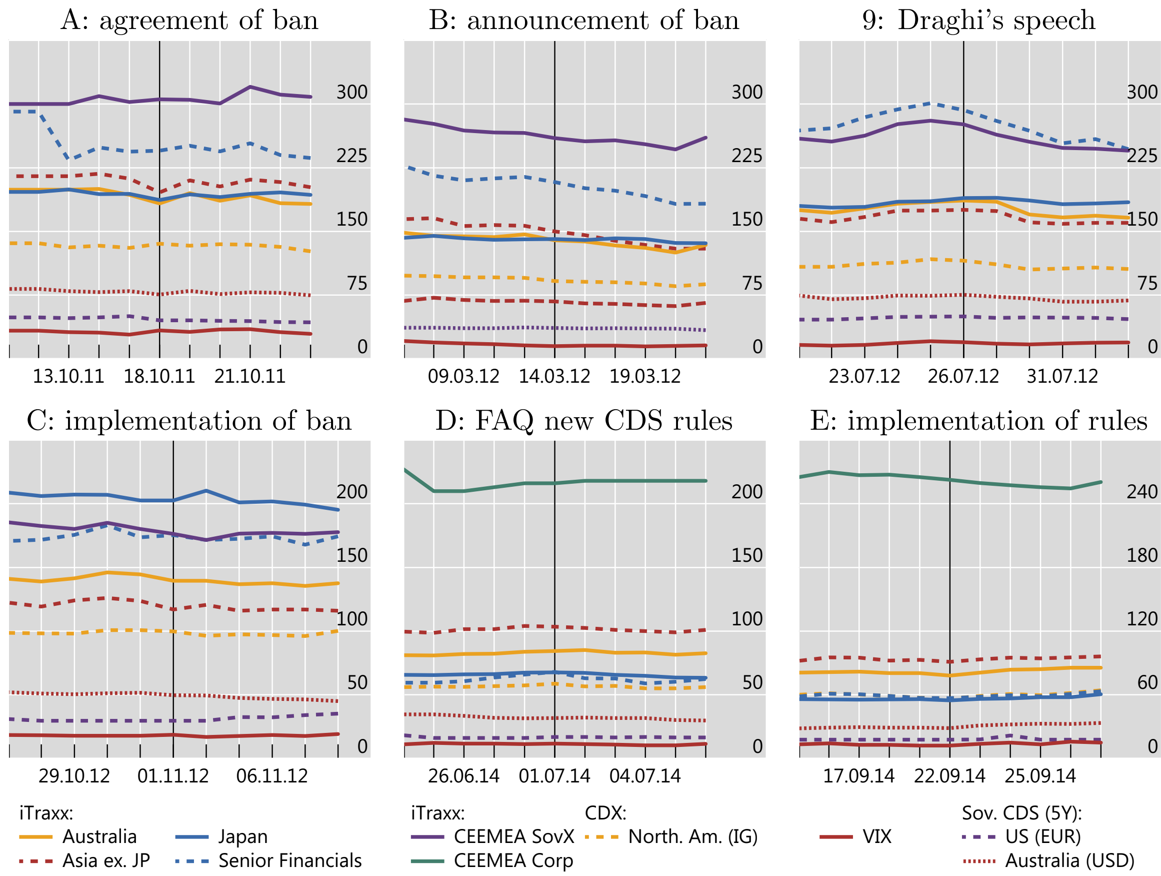
We have chosen a variety of instruments marking the credit market situation of the non-European sovereign CDS market and the corporate CDS market as well as the general state of financial markets. In particular, we study: six iTraxx indices (Australia, Asia-ex-Japan, CEEMEA Corp, Sovx CEEMEA, Europe Senior Financials, Japan), the CDX NA (IG) index, two single name CDS spreads (for USA and Australia) and the VIX volatility index and depict their time evolution around the policy intervention events A to E in Figure 6. Overall, we only see mild movements of these factors around A to E. This is especially remarkable, since the new ISDA rules equally concerned Euro area sovereign CDS as well as Australian and US CDS and CDS indices. Though around events D and E, these time series hardly change (see Figure 6). We conclude that around the time of the implementation of the new rules, only the Euro area sovereign CDS were under strong pressure and thus affected. In contrast, the implementation of the new ISDA rules did not matter for the pricing of the iTraxx and CDX indices as well as the US and Australian single name CDS spreads. Note that a formal regression analysis for short-term intervention effects is not possible as iTraxx, CDX, and VIX time series are only available on daily frequency, while we can observe connectedness effects on a high-frequency scale.

4.3 The impact of EAPs and unconventional monetary policy actions

We study eight main instances of policy interventions during the European sovereign debt crisis (see Table 4 in the Appendix for details). There are two types of interventions, namely the ones targeting a specific country such as the bailouts for Greece, Ireland, Portugal and the Spanish banks (events 1, 3, 4, 5 and 8 in Figure 2) and those with a primarily European focus such as the ECB's Securities Markets Program (SMP) (events 2 and 6 in Figure 2) and the Outright Monetary Transactions (OMT) which were announced by Draghi's speech "whatever it takes" (event 9 in Figure 2). We distinguish between actions until the second Greek Economic Adjustment Program (EAP), i.e. events 1-4, which happened before the enlargement of the European Financial Stability Facility (EFSF) at 21.07.2011 and those events occurring at and after the enlargement of the EFSF.

Figure 6: External factors

The figure shows the time evolution of six iTraxx indices (Australia, Asia-ex-Japan, CEEMEA Corp, Sovx CEEMEA, Europe Senior Financials, Japan), the CDX NA (IG) index, two single name CDS spreads (for USA and Australia) and the VIX index around the events A, B, 9, C, D, E (the labeling of events is as in Figure 2). We have as previously chosen 5 day pre- and post event windows.



We investigate the short-term aim of policy interventions to calm financial markets which positively impact fundamental fiscal and macroeconomic indicators (Commission, 2012). These then lead to a reduction in risk perception (Lucas et al., 2014) and hence CDS (excess) spreads (Aizenman et al., 2013) and spillovers (Caceres et al., 2010) because of decreasing speculation and contagion. As SMPs and EAPs directly target bonds, their impact on bond yields and consequently on asset swap spreads (ASW) (see O'Kane, 2000) is evident. Though, they also affect CDS spreads through an arbitrage relation with ASWs (see O'Kane, 2012). In contrast to Eser and Schwaab (2016), with high-frequency CDS data we can quantify the immediate effects of interventions and can determine their significance and sustainability over time which is key for disentangling impacts of closely consecutive policy actions.[24] Moreover, with the results of the previous subsection, we can put obtained impact magnitudes in context which is essential for judging the overall importance of the respective actions.

[24] However, we do not have access to their ECB proprietary data on program sizes.

We generally find (see Table 3) that the intervention impact from monetary actions and economic adjustment programs on contagious spillovers is substantially smaller than the overall reduction achieved by regulatory measures (see Table 1). A graphical comparison of the total connectedness around monetary interventions and economic adjustment programs in Figure 7 and around regulatory measures in Figure 3 also indicates that regulatory actions were more sustainable in terms of longer lasting reductions of spillovers. In the following, we take a closer look at differences in impact of European versus country-specific measures and "learning effects" reducing the impact of country-specific interventions over time.

4.3.1 Diminishing effects for repetitions of unconventional policy measures

We generally find that unconventional policy measures have a diminishing impact on contagion if repeated. Given their systematic decrease in effectiveness this could be largely due to learning effects in the markets where such measures have successively become less unconventional and have already been priced in by the time of their implementation (Borio and Zabai, 2016). This finding holds in particular for individual EAPs targeted at specific countries despite different country-specific circumstances (see Figure 7 for an overview). In all cases, their program sizes were aligned to the imbalances that had been built up before the crisis and their volume rather increased when implemented later in time (see Sapir et al. (2014)). Thus, when we find a diminishing effect of EAPs this is despite increasing volumes over time. In contrast, after the enlargement of the ESFS the European-wide first and second wave of the SMP were of the same format but fundamentally different due to a vastly larger volume in the second wave (€780bn versus €440bn in the first wave). Here the learning was on the ESFS side, since only this substantial increase in volume led to a substantial reduction Δ_I in contagion (see Table 3, upper parts of Panel A and B). Note that for speculation in the CDS levels, however, the effect Δ_I after the first SMP wave exceeds the impact of the second SMP wave so the impact was diminishing over time. Table 8 in the Appendix reveals that these findings also hold true consistently on a per country level.

For the EAP programs, we see from the Chow-test F-statistics in the upper tables in panel A and B of Table 3 that the impact of interventions on contagion was significant at each instance ($p_I^F = 0.00$) but vanished in magnitude when similar measures were repeated. Recall that for closely consecutive events it is not sufficient to only study constant intervention effects Δ_I, but we must additionally capture changes in trending slopes via Chow-tests. Thus, large corresponding F_I-values indicate large joint standardized changes in constant and slope of the underlying trend. The diminishing effect for repetitions is most evident for changes F_I in contagion of GR1 and GR2. If ignoring slope effects and only measuring changes in the overall mean level of connectedness Δ_I the measure is too coarse to disentangle effects of the SMP and the Greek EAP. For such event clusters, we rather study joint sustainable effects in Δ before the begin of the cluster and after the end for comparison to regulatory intervention effects. This is especially insightful when investigating effects on the per country level (Table 8) where we see substantial reduction in contagion after the enlargement of the ESFS for almost all countries (according to Δ-values). Also when comparing the impact of

Table 3: Intervention impact of EAPs and monetary policy actions

For each policy intervention I, we evaluate its impact by assessing spillovers right before the action and afterwards. The table presents time aggregates in mean with respective empirical standard deviations in parentheses of connectedness over a window of 90 observations (The Irish and Portuguese EAP is well separated from other events. Therefore, we have used 200 observations for these EAPs to achieve higher statistical significance.) before the intervention $\overline{I-}$ or after $\overline{I+}$ where the main post-I reference period is taken 5 days distant to the event due to the respective VAR-estimation lag in the construction of the spillovers in Equation (4). The p-value of the respective two-sample significance test for a constant level (spillover) in the time interval of $\overline{I-}$ and $\overline{I+}$ is reported as p_I. The intervention impact is measured as Δ_I marking the relative change $((\overline{I+}) - (\overline{I-}))/(\overline{I-})$ in %. Results are reported for total connectedness and CDS spreads for different policy actions. The numbering I of events in the first column is as in Figure 2. The last two columns show test results of the Chow test, where the normalized test statistics F_I measures the strength of the change of a linear trend in the series due to the event.

Panel A: Bailout programs before the enlargement of ESFS

Total connectedness

I	Event	$\overline{I-}$	$\overline{I+}$	p_I	Δ_I	F_I	p_I^F
1	GR1	0.59(0.03)	0.78(0.07)	0.00	32.20	826.64	0.00
2	SMP1	0.68(0.02)	0.73(0.03)	0.00	7.35	402.53	0.00
3	IE	0.56(0.03)	0.48(0.12)	0.00	-14.29	246.36	0.00
4	PT	0.59(0.06)	0.70(0.03)	0.00	18.64	262.81	0.00

Average CDS levels

I	Event	$\overline{I-}$	$\overline{I+}$	p_I	Δ_I	F_I	p_I^F
1	GR1	219.04(31.13)	267.82(101.57)	0.00	22.27	285.12	0.00
2	SMP1	272.88(42.30)	191.86(13.39)	0.00	-29.69	57.51	0.00
3	IE	371.94(26.76)	369.91(10.30)	0.34	-0.55	527.99	0.00
4	PT	433.22(24.32)	436.90(13.51)	0.07	0.85	194.26	0.00

Panel B: Bailout programs after the enlargement of ESFS

Total connectedness

I	Event	$\overline{I-}$	$\overline{I+}$	p_I	Δ_I	F_I	p_I^F
5	GR2	0.70(0.05)	0.60(0.10)	0.00	-14.29	11.18	0.00
6	SMP2	0.64(0.09)	0.60(0.04)	0.00	-6.25	1182.29	0.00
8	ES	0.45(0.03)	0.54(0.03)	0.00	20.00	354.14	0.00
9	Draghi	0.54(0.05)	0.47(0.04)	0.00	-12.96	134.95	0.00

Average CDS levels

I	Event	$\overline{I-}$	$\overline{I+}$	p_I	Δ_I	F_I	p_I^F
5	GR2	777.67(51.14)	600.20(20.20)	0.00	-22.82	912.38	0.00
6	SMP2	634.16(16.78)	615.06(19.02)	0.00	-3.01	32.79	0.00
8	ES	451.11(6.52)	477.70(14.33)	0.00	5.89	411.15	0.00
9	Draghi	382.27(10.37)	441.04(12.74)	0.00	15.37	1670.72	0.00

changes in connectedness F_I of the EAPs of Ireland, Portugal and Spain to the one by the first EAP of Greece, the effects are only half or a third of the size and only the Irish EAP lead to a negative overall effect Δ. Moreover, for reducing contagion Draghi's speech seemed overall negligible from Table 3, while for speculation in levels it had the largest overall change effect. Though Table 8 reveals that Draghi's speech also had a substantial impact on reducing contagion on a per country level. Here, Portugal is at a very low absolute level of contagion and thus dilutes the aggregated picture.

4.3.2 Impact of European-wide measures versus single country actions and other external factors

For unconventional policy interventions, it is their scope which matters most for judging the significance and persistence of their impact on contagion and speculation. Generally European-wide interventions have a stronger and longer lasting effect than events which only target a particular country. Comparing F_I-magnitudes in Table 3 we find the largest values in the lower panel, 1182.29 and 1670.72, connected to the second implementation of the SMP and the Draghi speech, respectively. In the case of the first implementation of the SMP, the F_I-value for changes in average CDS levels is small, but we find a strong constant level impact $\Delta = -29.69\%$ (see Table 3 and also Figure 7(a)). For total connectedness effects of the first SMP, we get a larger F_I than for the two subsequent bailouts, suggesting a stronger change impact of the first SMP on contagion.[25] The longer term effectiveness can be inferred from Figure 2 which puts the time incremental effects in a longer run perspective for total connectedness. After the first SMP, we see some calming of markets, which was interrupted by the Irish and Portuguese economic crisis. The corresponding adjustment programs did not result in a longer-term reduction in spillovers. Only after the second SMP we find a leveling out. A similar effect is found after Draghi's speech. For a shorter time window, we see the leveling out (even a reduction) in CDS spreads and spillovers in Figure 7(d) after Draghi's speech.

In the following we study the potential influence of other factors such as liquidity but also the general (sovereign) credit market and financial market situation on the determined intervention effects.

Liquidity

Figure 8 shows that liquidity can be excluded as a driving factor for the measured intervention effects in Table 3. Except for the first Greek EAP and the subsequent SMP (events 1 & 2), liquidity remained almost constant. Even though liquidity declines after the surprise of the first Greek EAP and the SMP, the bid-ask-spread just reaches pre-sovereign debt crisis levels (compare with the figure on the very left-hand side). The advantage of our intraday data is that we can use very small windows to avoid the impact of other events, so we can confidently claim that the reported Δ_I and F_I values are due to the investigated events. For the time evolution of bid ask spreads see also Figure 14 in Appendix A.4. We also confirm these findings by two further proxies of liquidity, namely net notional amounts outstanding and number of trade counts (see Figure 15 in Appendix A.4).

[25] Note that the first Greek bailout is special, as it came at a surprise, violating the Maastricht treaty.

Other external factors

Similarly to Subsection 4.2.2, we also investigate the potential impact of other external factors on the determined intervention effects. As before we study iTraxx indices, the VIX and two single name sovereign CDS spreads in Figure 9 around the respective intervention dates. None of these factors changes substantially before and directly after the economic adjustment programs or Draghi's speech. The situation, however, differs for the two implementations of the SMP which had an overall stronger effect on reducing contagion and speculation than the individual EAPs. Hence Figure 9 clearly depicts that these actions also influenced corporate credit markets and other non-European sovereign credit markets. Though, these effects occurred only simultaneously to or after the intervention. Hence, in line with our discussion in Subsection 4.2.2, we can attribute the movements of our Euro area sovereign CDS spreads and connectedness measures to the EAPs and SMPs. Due to data availability and data quality during the considered period, we can only consider a smaller number of indicators than in Subsection 4.2.2 but we still capture the main external credit and market type effects with them. Please note that as before a formal regression type analysis explicitly controlling for the external factors is not possible because of the only daily observation frequency of the instruments and thus less then 10 observations in the evaluation period for the intervention effect.[26]

[26] Also for longer term effects, a regression setting would be of limited help since then closely subsequent timing of the interventions would not allow to disentangle impacts.

Figure 7: Total spillovers and level effects around EAPs and monetary policy actions

In each panel, the figure illustrates the time evolution of total connectedness (right) and CDS spreads (left) around policy events. We consider the first Greek EAP and the first European-wide SMP in panel (a) (events 1 at 28.04.2010 and 2 at 10.05.2010), the Irish and Portuguese EAP in panel (b) (events 3 at 30.11.2010 and 4 at 03.05.2011), the second Greek EAP and the second European-wide SMP in panel (c) (events 5 at 21.07.2011 and 6 at 08.08.2011), and the Spanish EAP and Draghi's speech in panel (d) (events 8 at 26.07.2012 and 9 at 27.07.2012). The respective right-hand figures depict the total amount of spillover effects in the network measured as $\tilde{s}$ calculated from the $GFEVD$ components in Equation (4) in red solid lines with 90% pointwise confidence intervals in shaded red. The figures on the left (apart from (b)) show the country-wise evolution of CDS spreads. In all graphs, the grey area marks the post-event period after which effects should be evaluated given the 5 day estimation time-lag of the VAR dynamic in the rolling windows. In all cases, a rolling window size of $T_e = 90$ observations is used. The labeling of events is as in Figure 2.

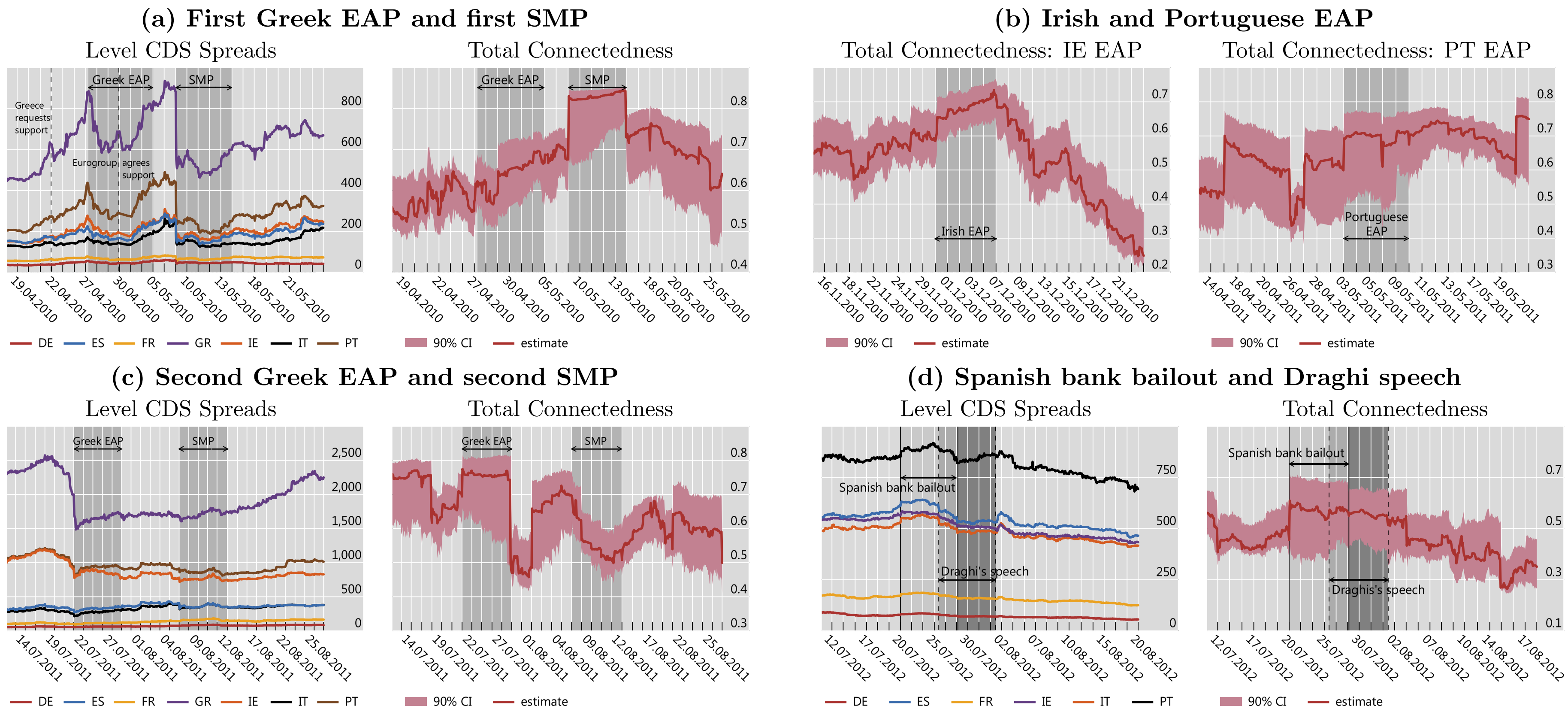


Figure 8: Liquidity

The figure illustrates the relative bid-ask spreads as liquidity proxy defined as (ask price-bid price)/((ask price+bid price)/2) of CDS-spreads around the economic adjustment programs, the SMP and Draghi's speech. As in Table 1, boxplots are calculated for time averages in two distinct windows of 200 observations each before and after the event varying in the cross-section of countries. The labeling of events is as in Figure 2.

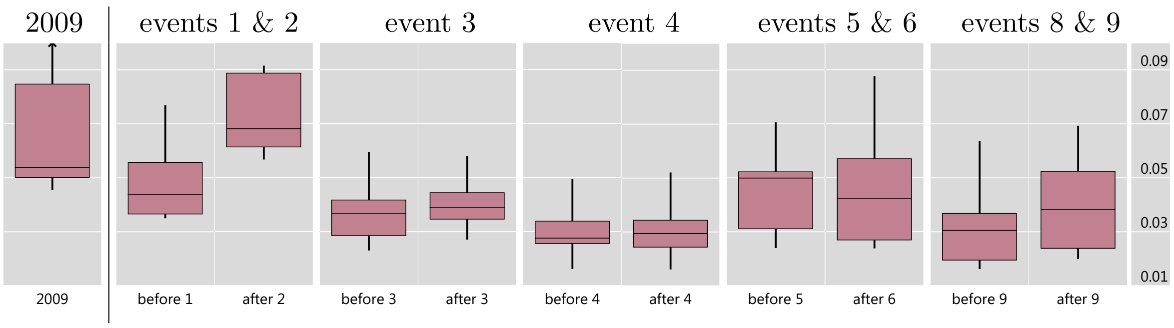
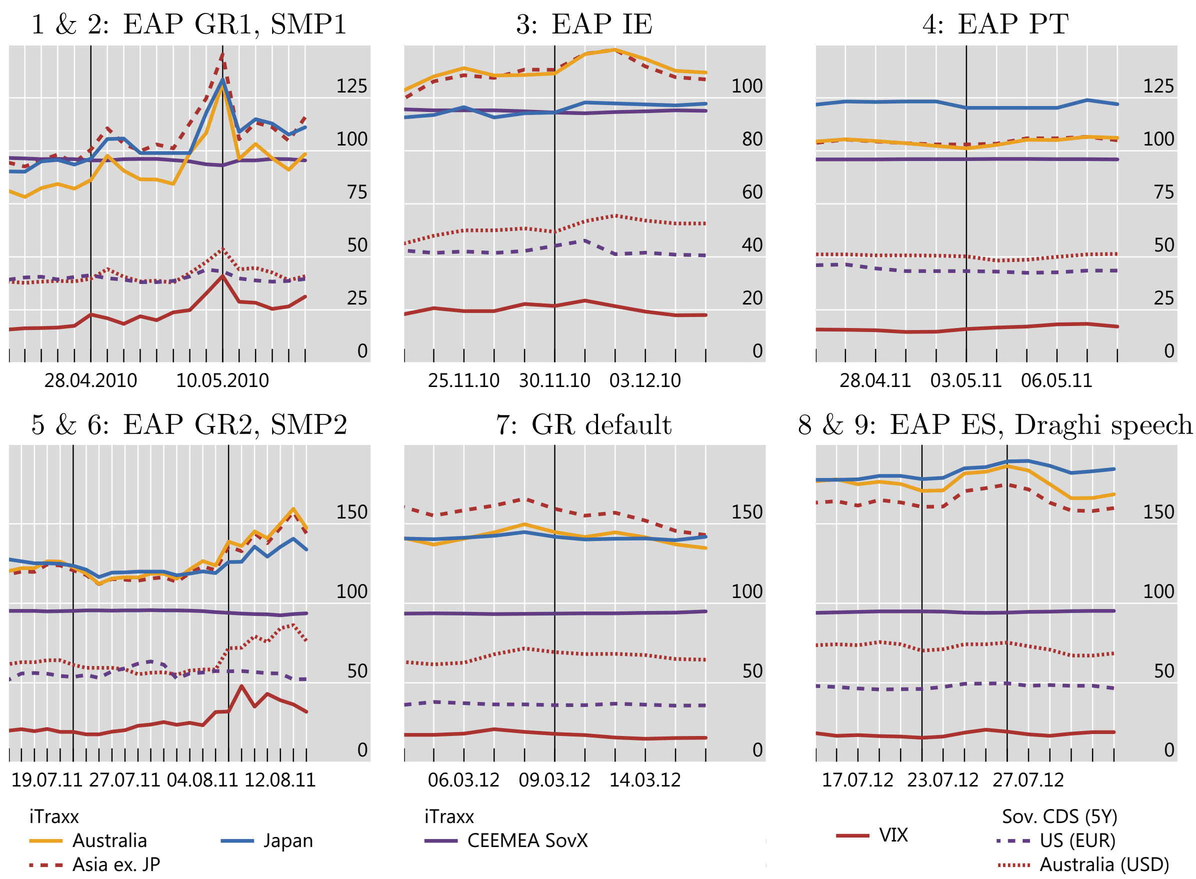


Figure 9: External factors

The figure shows the time evolution of four iTraxx indices, the VIX and two single name sovereign CDS spreads around the events 1 to 9 (the labeling of events is as in Figure 2). We have as previously chosen 5 day pre- and post event windows.



4.4 Effects on the network topology

When studying intervention effects on the granular spillover network level, we determine that interventions had an overall stabilizing effect. Throughout and in particular also at the end of the sovereign crisis, we only find spillover networks among European sovereigns that can be characterized as balanced. That means we do not observe fragmentation defined as a split-up of the network into independent sub-networks (fragments).[27] Also, we do not detect a centering of an impaired country such as Greece in the network structure. Generally, such balanced networks with a complete structure have been documented as the most robust against contagion (see, e.g. Allen and Gale, 2000; Freixas et al., 2000; Upper, 2011). While the balanced structure of a network might cause the scope and width of the propagation of a shock through the network to widen in some cases, maximum entropy techniques show that the spillover intensity of each link in this form is much smaller yielding an overall reduced level of contagion in comparison to other topologies (Mistrulli, 2007; Gai and Kapadia, 2010; Acemoglu et al., 2015). Thus, from a regulator's perspective a balanced network with weak contagion links is the most preferable scenario for mitigating systemic risk. Our empirical findings are in contrast to existing empirical studies using daily bond yields such as e.g Ehrmann and Fratzscher (2017), Santis (2014) or Caporin et al. (2018) where the latter even find evidence for disintegration as still on-going at the end of their sample in April 2013. Though, in contrast to CDS spreads, the bond market was driven by flight-to-safety effects and hence was directly impacted by the SMP and OMT. Thus for assessing credit risk, CDS based measures are more suitable than bonds (see, e.g. Pan and Singleton, 2008; Ang and Longstaff, 2011).

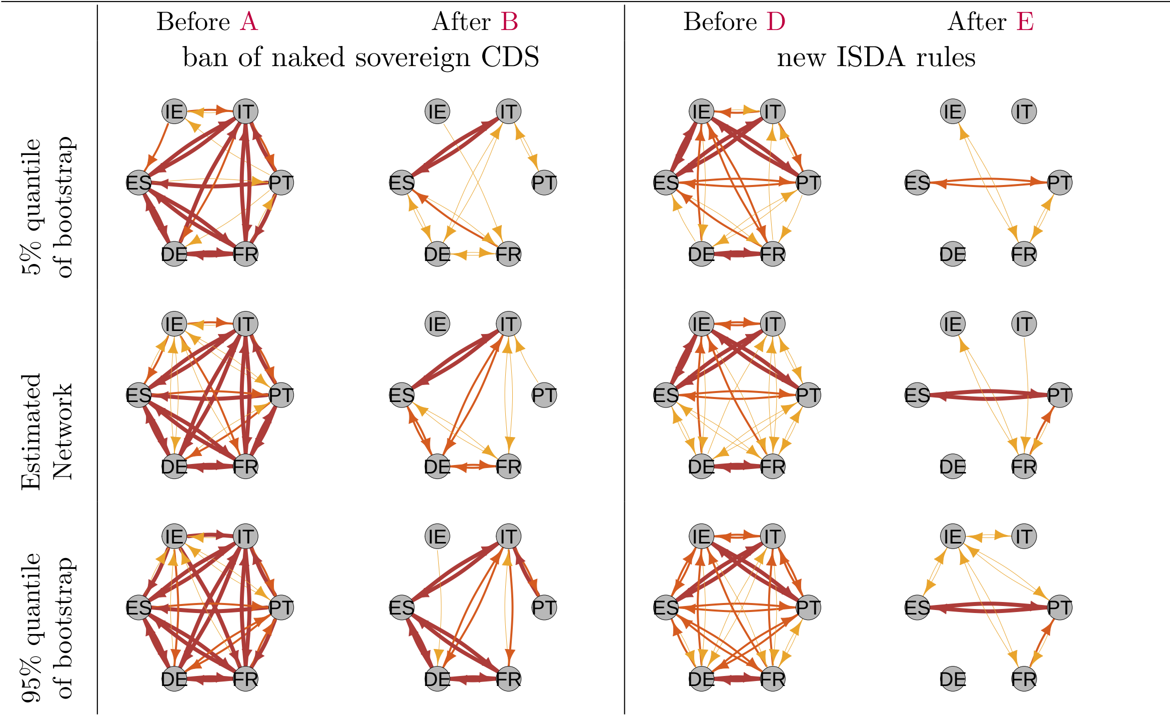
In particular, in Figure 10, we observe a statistically significant reduction of spillover channels between the agreement of the permanent ban of naked sovereign CDS trading (end 2011, marked as A in Figure 10) and the announcement of the technical details of the ban (beginning 2012, marked as B). Thus not only the magnitude of contagion in the market dropped as determined in Subsection 4.2.1, but also the amount of significant spillover channels decreased. Note that the upper and lower line of Figure 10 effectively report a spillover confidence interval for each link in the contagion network which can be determined from our bootstrap procedure per link. This allows to determine significant reductions in spillover channels when interconnections vanish in both the upper and lower lines. Such reductions are a much stronger statement than only a reduction in point estimates in the middle line. An even more drastic effect in reduction of spillover channels is achieved by the new ISDA rules between their implementation (event E in Figure 10) and their announcement (D). As seen before, this also coincides with a reduction in magnitude of the overall and country-wise levels of connectedness (see Table 1). Similar to the ban, the network also remains balanced without fragmentation after the ISDA rules.

For the unconventional policy interventions and in particular the country-specific EAPs, impacts on the granular network spillover structure are substantially different with a generally

[27] Ehrmann and Fratzscher (2017) define fragmentation as a reduction in credit risk spillovers, while we define fragmentation as used in colloquial language.

Figure 10: Evolution of connectedness linked to the CDS ban and the new ISDA rules

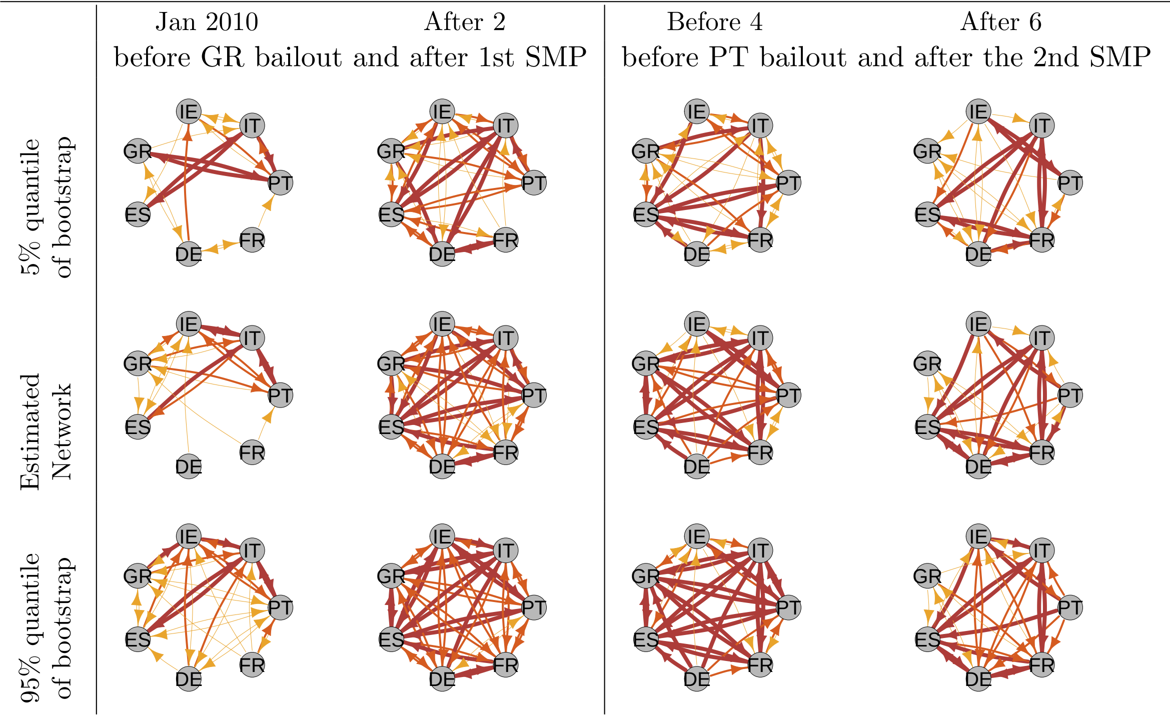
The figure illustrates individual connectedness in form of network graphs including estimates (middle), lower confidence interval boundary (top) and upper confidence interval boundary (bottom). The network graphs are computed with five trading day windows. Nodes represent countries and arrows represent individual connectedness measures, e.g. an arrow from country j to country i visualizes $\widetilde{s}_{ij}$ (see Equation (1)). The width and colour of the connecting lines indicate the strength of the connectedness: bold red lines indicate strong connectedness (fourth quartile), orange lines indicate upper medium connectedness (third quartile), thin yellow line indicate lower medium connectedness (second quartile) and no connecting line indicates small connectedness (first quartile). The arrows at each line show the directedness of the connectedness.



increasing amount of channels. In particular, the amount of connectedness channels rises substantially between the end of 2009 and the first Greek bailout in April 2010, leading to a strong integration of the sovereign network (see left-hand side in Figure 11). This increase in connection with an increasing overall magnitude of total connectedness at the beginning of the sovereign debt crisis is comparable to "wake-up call" contagion as identified for the bond market by Giordano et al. (2013). Before the first Greek bailout (a violation of the Maastricht treaty), we can see two separated groups of countries in the network (see left-hand panel in Figure 11). The first group consists of peripheral countries, which are strongly connected among each other. The second fragment consists of France and Germany, which are weakly connected with other countries. This observation is in contrast to results of Ehrmann and Fratzscher (2017) for bond markets. Our analysis clearly shows two effects on the network after the Greek bailout and the SMP: It becomes more balanced or less fragmented while the overall level of total connectedness decreases significantly in size (see Figure 7). After the SMP, France and Germany also share credit risk of the crisis countries due to the common bailout facility. After the first Greek bailout and implementation of the SMP, the balanced structure of the network remains relatively stable. The bailouts for Ireland and Portugal and the "whatever it takes" speech do not induce a significant change in the amount of significant individual volatility spillover links. Even though total connectedness decreases after the bailout of Ireland, the network connections mostly remain the same. In particular, this is illustrated in the confidence sets for links instead of just the point estimates. An important exception to the unaltered networks, however, is the isolation of Greece between the Portuguese bailout and the second Greek bailout and SMP implementation (see right-hand panel of Figure 11). Thanks to this isolation and the reduced exposure of financial intermediaries to Greece its (official) default on 09.03.2012 did not strongly affect other countries in the network.

Figure 11: Evolution of connectedness linked to the Greek and Portuguese bailout

The figure illustrates individual connectedness in form of network graphs. For details we refer to Figure 10.



5 Robustness

In this section we investigate the robustness of our findings with respect to the dynamic model specification, the variance decomposition method and the choice of countries in our network. Furthermore, we also discuss in more detail how we handle missing values in our data set.

5.1 Dynamic specification and decomposition method

We confirm the adequacy of the chosen dynamic VAR-specifications and rolling window sizes empirically with an OLS-based MOSUM stability test (Chu et al., 1995; Kuan and Hornik, 1995) which yields evidence of no structural breaks for rolling window sizes of 90 and 180 observations at a significance level of 10%. This is in line with Blatt et al. (2015), who show that structural breaks are less important for small estimation windows. We also verify that heteroscedastic effects are negligible in our data set by applying an ARCH-LM-test as proposed by Engle (1982) and a multivariate Portemanteau test for serial correlation, adjusted for small sample sizes to each estimation window. Since the most important part of the data is not significantly affected by heteroscedasticity[28] and in favor of a parsimonious model we exclude heteroscedastic effects from the model. Thus an underlying VAR dynamic specification in rolling windows in Equation (2) captures the system dynamics in an adequate way. While the lag length p is determined from the data, also different VAR-type specification such as including a constant in Equation (2) yield no systematic difference in connectedness results.

Our obtained network results are independent from our underlying dynamic model specification and variance decomposition method. We illustrate this in Figure 12 by comparing the total connectedness derived from s_{ij} of the variance decomposition in Equation (4) to the one based on the realized correlation s_{ij}^d. The realized correlation is a model-free connectedness measure:

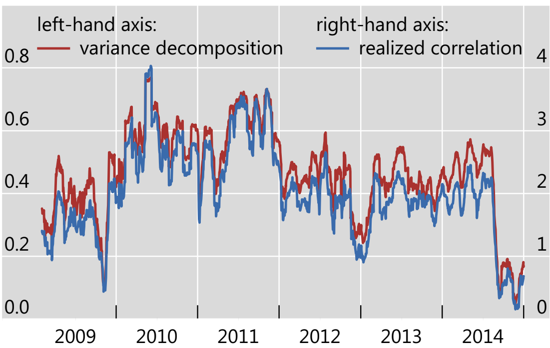
$$s_{ij}^d := RCorr_{ij} = \frac{\sum_{t=1}^{T'} y_{ti} y_{tj}}{\sqrt{\sum_{t=1}^{T'} y_{ti}^2 \sum_{t=1}^{T'} y_{tj}^2}} \tag{5}$$

expressed in rolling windows of length T' over time $t = 1, \ldots, T$.

In Figure 12 we see that the dynamics of the two measure are very similar. Therefore, the dynamics of the resulting connectedness measures does not appear to be impacted by specification choices of the underlying model.

Figure 12: Realized correlation versus variance decomposition

The figure shows the total connectedness based on correlation and on variance decomposition. The rolling window size for both methods is 20 trading days.



[28] Results of both tests show that for the large part, the null of no heteroscedasticity cannot be rejected. The only exception to this is the period before October 2010 for ARCH-tests and the last part of the data after December 2013 for the Portemanteau test in which only few rolling windows show evidence for heteroscedasticity.

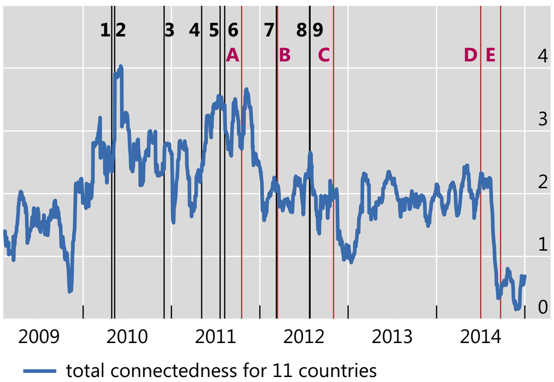
Thus we conclude that our empirical results are not specific to the variance-decomposition type of spillover measures. However, the variance decomposition allows to compute confidence intervals and conduct significance tests.

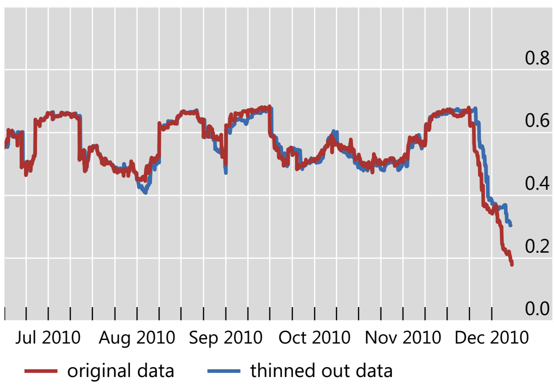
5.2 Data

We also evaluate the robustness of the connectedness measure with respect to the countries selected. For this purpose we compute the time evolution of overall connectedness by including four additional Euro area members: Austria, Belgium, Finland and the Netherlands. The results presented in Figure 13 (left-hand panel) show an almost identical behavior as in Figure 2.

Figure 13: Robustness with respect to data set specification

On the left, the figure illustrates the overall connectedness based on CDS data for the extended set of 11 countries: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Portugal, Spain and the Netherlands. For details on the labeling of the events, we refer to Figure 2. On the right-hand side, the figure illustrates a robustness check with respect to the influence of missing observations on total connectedness. As an illustration, the total connectedness of two data sets is compared: the original data for a chosen time period in 2010 and same data set manipulated such that the data availability is as in early 2009 and late 2014.





During the considered time period, our CDS intraday dataset contains a smaller number of observations in 2009 and the second half of 2014 (see Table 5). Since it is open if this is an artefact of a change in data cleaning and aggregation procedures of our data provider CMA or accurately reflects less trades in the market, we check for robustness of our results with respect to the artefact situation.

Hence we assess if a reduced number of observations as in 2009 or in the second half of 2014 affects the connectedness measure. To this end, we gather the structure of missing values from July to December 2014 and delete these values for the subsample covering July to December 2010 (amounting to 183 deleted observations of a total of 2,231 observations). The connectedness measures based on the original subsample of 2010 are similar to those based on the same subsample with deleted values, as can be seen in the right-hand panel of

Figure 13. Thus we conclude that the relatively low connectedness in 2009 and the drop of connectedness in 2014 is not due to a lower number of observations.

6 Conclusion

We analyse the effectiveness of regulations and policies during the Euro area sovereign debt crisis, from 2009 until end 2014. This period includes the main country-wise EAPs but also European-wide measures such as the two SMPs as well as regulatory changes such as the ban of naked CDS and the implementation of the new ISDA rules.

Overall, we find that the impact of the regulatory interventions is substantially larger than the effect of policy actions - both in reducing the overall level of contagion as well as the amount of spillover channels. Moreover among the policy interventions, we find that programs targeting single countries, e.g. the economic adjustment programs, are less effective than European-wide programs such as the SMPs in reducing overall contagion while increasing spillover links to a more balanced structure. Also effects of unconventional policy measures diminish when they are implemented more than once unless counteracted by an increase in the size of the intervention. Further, during the crisis we find balanced networks, i.e. no fragmentation, with the only exception of a slight isolation of Greece before the official Greek default.

With high-frequency data, we can disentangle impacts of closely consecutive effects. For our assessment we also provide a bootstrap procedure which allows to assess if overall network effects as well as individual network links are indeed significant. Thus we can formally test for significance in changes in the overall level but also the trending behaviour of total and countrywise network spillovers.

Our paper indicates that the implemented policy and regulatory measures helped at a different degree to substantially reduce contagion and speculation during the European debt crisis. In particular, regulatory actions played a key role in contrast to the EAPs or monetary policy measures where the effect was only short-term. Hence in severe crisis situations, monetary policy actions can only pave the way until regulatory adjustments are taken.

References

Acemoglu, D., A. Ozdaglar, and A. Tahbaz-Salehi (2015): "Systemic Risk and Stability in Financial Networks," *American Economic Review*, 105, 564–608.

A.Chan-Lau, J. (2017): "Variance Decomposition Networks: Potential Pitfalls and a Simple Solution," IMF Working Papers 17/107, International Monetary Fund.

Ahelegbey, D. F., M. Billio, and R. Casarin (2016): "Bayesian Graphical Models for STructural Vector Autoregressive Processes," *Journal of Applied Econometrics*, 31, 357–386, jae.2443.

Aizenman, J., M. Hutchison, and Y. Jinjarak (2013): "What is the risk of European sovereign debt defaults? Fiscal space, CDS spreads and market pricing of risk." *Journal of International Money and Finance*, 34, 37–59.

Allen, F. and D. Gale (2000): "Simulation methods to assess the danger of contagion in interbank markets," *Journal of Political Economy*, 108, 1 – 33.

Alter, A. and A. Beyer (2014): "The dynamics of spillover effects during the European sovereign debt crisis," *Journal of Banking and Finance*, 134–153.

Ang, A. and F. Longstaff (2011): "Systemic sovereign credit risk: Lessons from the US and Europe," NBER Working Papers 16983, National Bureau of Economic Research, Inc.

Arghyrou, M. and A. Kontonikas (2012): "The EMU sovereign-debt crisis: Fundamentals, expectations and contagion," *Journal of International Financial Markets, Institutions and Money*, 22, 658–677.

Beber, A. and M. Pagano (2013a): "Short-Selling Bans Around the World: Evidence from the 2007-09 Crisis," *Journal of Finance*, 68, 343–381.

——— (2013b): "Short-Selling Bansaround the World: Evidence from the 20072009 Crisis," *Journal of Finance*, 68, 343–381.

Betz, F., N. Hautsch, T. A. Peltonen, and M. Schienle (2016): "Systemic risk spillovers in the European banking and sovereign network," *Journal of Financial Stability*, 25, 206 – 224.

Blatt, D., B. Candelon, and H. Manner (2015): "Detecting contagion in a multivariate time series system: An application to sovereign bond markets in Europe," *Journal of Banking & Finance*, 59, 1–13.

Boehmer, E., C. Jones, and X. Zhang (2013): "Shackling Short Sellers: The 2008 Shorting Ban," *Review ofFinancial Studies*, 26, 1363–1400.

Boehmer, E. and J. Wu (2013): "Short Selling and thePrice Discovery Process," *Review of Financial Studies*, 26, 287322.

Borio, C. and A. Zabai (2016): "Unconventional monetary policies: a re-appraisal," BIS Working Paper 570, Bank for Internationale Settlements.

Buse, R. and M. Schienle (2019): "Measuring Connectedness of Euro Area Sovereign Risk," *International Journal of Forecasting*, 25, 25–44.

Caceres, C., V. Guzzo, and M. Segoviano (2010): "Sovereign Spreads: Global Risk Aversion, Contagion or Fundamentals?" Working Paper 10/120, International Monetary Fund.

Caporin, M., L. Pelizzon, F. Ravazzolo, and R. Rigobon (2018): "Measuring sovereign contagion in Europe," *Journal of Financial Stability*, 34, 150 – 181.

Che, Y.-K. and R. Sethi (2014): "Credit market speculation and the cost of capital," *American Economic Journal*, 6, 1–34.

Chu, C.-S. J., K. Hornik, and C.-M. Kaun (1995): "MOSUM tests for parameter constancy," *Biometrika*, 82, 603–617.

Claeys, P. and B. Vašíček (2012): "Measuring Sovereign Bond Spillover in Europe and the Impact of Rating News," Working Papers 2012/07, Czech National Bank, Research Department.

——— (2014): "Measuring Bilateral Spillover and Testing Contagion on Sovereign Bond Markets in Europe," Working Papers 1666, European Central Bank.

Commission, E. (2011): "Regulation on Short Selling and Credit Default Swaps - Frequently asked questions," Memo 11/713, European Commision.

——— (2012): "The Second Economic Adjustment Programme for Greece." Occassional Papers 94, European Commission.

Constâncio, V. (2012): "Contagion and the European debt crisis," *Financial Stability Review, Banque de France*, 16, 109–121.

Daniels, K. N. and M. S. Jensen (2005): "The Effect of Credit Ratings on Credit Default Swap Spreads and Credit Spreads," *The Journal of Fixed Income*, 15, 16–33.

De Santis, R. A. and S. Zimic (2018): "Spillovers among sovereign debt markets: Identification through absolute magnitude restrictions," *Journal of Applied Econometrics*, 33, 727–747.

Diebold, F. and K. Yilmaz (2009): "Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets," *Economic Journal*, 119, 158–171.

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

Dornbusch, R., Y. C. Park, and S. Claessens (2000): "Contagion: Understanding How It Spreads," *The World Bank Research Observer*, 15, 177–197.

Duffie, D. (2010): "Is there a case for banning short speculation in sovereign bond markets?" *Financial Stability Review*, 55–59.

Ehrmann, M. and M. Fratzscher (2017): "Euro area government bonds Fragmentation and contagion during the sovereign debt crisis," *Journal of International Money and Finance*, 70, 26 – 44.

Engle, R. (1982): "Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation," *Econometrica*, 50, 987–1007.

Engle, R., E. Jondeau, and M. Rockinger (2014): "Systemic Risk in Europe," *Review of Finance*, 1–46.

Eser, F. and B. Schwaab (2016): "Evaluating the impact of unconventional monetary policy measures: Empirical evidence from the ECBs Securities Markets Programme," *Journal of Financial Economics*, 119, 147–167.

Falagiarda, M. and S. Reitz (2015): "Announcements of ECB unconventional programs: Implications for the sovereign spreads of stressed euro area countries," *Journal of International Money and Finance*, 53, 276 – 295.

Forbes, K. J. and R. Rigobon (2002): "No Contagion, Only Interdependence: Measuring Stock Market Comovements," *Journal of Finance*, 57, 2223–2261.

Freixas, X., B. Parigi, and J. Rochet (2000): "Systemic risk, interbank relations and liquidity provision by the central bank," *Journal of Money, Credit and Banking*, 32, 611638.

Gai, P. and S. Kapadia (2010): "Contagion in financial networks," *Proceedings of the Royal Society*, 466, 2401–2423.

Ghysels, E., A. Sinko, and R. Valkanov (2007): "MIDAS regressions: Further results and new directions," *Econometric Reviews*, 26, 53–90.

Gibson, H. D., S. G. Hall, and G. S. Tavlas (2016): "The effectiveness of the ECB's asset purchase programs of 2009 to 2012," *Journal of Macroeconomics*, 47, 45 – 57, what Monetary Policy Can and Cannot Do.

Giordano, R., M. Pericoli, and P. Tommasino (2013): "Pure or Wake-up-Call Contagion? Another Look at the EMU Sovereign Debt Crisis," *International Finance*, 16, 131–160.

Gros, D., C. Alcidi, A. Belke, L. Coutinho, and A. Giovannini (2014): "Implementation of the Macroeconomic Adjustment Programmes in the Euro Area: State-of-Play," CEPS Papers 9017, Centre for European Policy Studies.

Gyntelberg, J., P. Hoerdahl, K. Ters, and J. Urban (2013): "Intraday dynamics of euro area sovereign CDS and bonds," BIS Working Papers 423, Bank for International Settlements.

——— (2018): "Price discovery in euro area sovereign credit markets and the ban on naked CDS," *Journal of Banking and Finance*, 96, 106–125.

Hamilton, J. D. (1994): *Time Series Analysis*, Princeton Universiy Press.

Hautsch, N., J. Schaumburg, and M. Schienle (2015): "Financial Network Systemic Risk Contributions," *Review of Finance*, 19, 685–738.

IMF (2010): "Greece: Letter of Intent, Memorandum of Economic and Financial Policies, and Technical Memorandum of Understanding," .

Jeff Fleming, J., C. Kirby, and B. Ostdiek (1998): "Information and volatility linkages in the stock, bond, and money markets," *Journal of Financial Economics*, 49, 111–137.

Kiesel, F., F. Lücke, and D. Schiereck (2015): "Regulation of uncovered sovereign credit default swaps evidence from the European Union," *The Journal of Risk Finance*, 16, 425–443.

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

Kuan, C.-M. and K. Hornik (1995): "The generalized fluctuation test: A unifying view," *Econometric Reviews*, 14, 135–161.

Lucas, A., B. Schwaab, and X. Zhang (2014): "Conditional Euro Area Sovereign Default Risk." *Journal of Business and Economic Statistics*, 32(2), 271/284.

Lütkepohl, H. (2000): *Bootstrapping impulse responses in VAR analyses*, Heidelberg: Physica-Verlag HD, 109–119.

——— (2006): *New Introduction to Multiple Time Series Analysis*, Springer.

Mistrulli, P. (2007): "Assessing financial contagion in the interbank market: maximum entropy versus observed interbank lending patterns," Working Papers 641, Bank of Italy.

Neil, B. and J.-F. Fillion (1999): "An Intraday Analysis of the Effectiveness of Foreign Exchange Intervention," Staff Working Papers 99-4, Bank of Canada.

Oehmke, M. and A. Zawadowski (2015): "Synthetic or Real? The Equilibrium Effects of Credit Default Swaps on Bond Markets," *The Review of Financial Studies*, 28, 3303–3337.

O'Kane, D. (2000): "Introduction to asset swap spreads," Technical report, Lehman Brothers.

——— (2012): "The link between eurozone sovereign debt and CDS prices," Technical report, EDHEC-Risk Institute.

Pan, J. and K. Singleton (2008): "Default and recovery implicit in the term structure of sovereign CDS spreads." *The Journal of Finance*, 63, 2345–84.

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

Portes, R. (2010): "Ban Naked CDS," *Eurointelligence*.

Santis, R. A. D. (2014): "The euro area sovereign debt crisis: Identifying flight-to-liquidity and the spillover mechanisms," *Journal of Empirical Finance*, 26, 150 – 170.

Sapir, A., G. B. Wolff, C. de Sousa, and A. Terzi (2014): "The Troika and financial assistance in the euro area: successes and failures," Committee study, European Parliament.

Silva, P. P., C. Vieira, and I. Vieira (2016): "The EU Ban on Uncovered Sovereign Credit Default Swaps: Assessing Impacts on Liquidity, Volatility, and Price Discovery," *The Journal of Derivatives*, 23, 74 – 98.

Trichet, J.-C. (2002): "Asset price bubbles and their implications for monetary policy and financial stability," BIS Review 28/202, Bank for Internationale Settlements.

Upper, C. (2011): "Simulation methods to assess the danger of contagion in interbank markets," *Journal of Financial Stability*, 7, 111 – 125.

Vergote, O., E. Ghysels, J. Idier, and S. Manganelli (2017): "A high frequency assessment of the ECB securities markets programme," *Journal of the European Economic Association*, 15, 218–243.

A Appendix

A.1 Overview of Crisis Related and Regulatory Events

The sequence of regulations and crisis related events including the total connectedness and the 90% confidence interval is presented in Figure 2. The crisis related events are in black and regulatory events in purple. The choice of the dates in an event study is not straightforward. Usually there is a close schedule of meetings and announcements in the run-up to an event, whereby different amounts of information are released or even leaked. For example, the new ISDA rules have been discussed long before mid-2014. The ISDA published proposed amendments to the 2003 Credit Derivatives Definitions already on Tuesday 15.07.2013. Nevertheless, we have chosen 01.07.2014 (communication of the details of the rules) and 22.09.2014 (implementation of the rules) as the key dates. In our analysis we have experimented with different timing of the exact dates (see Table 4). The dates used in our calculations are boldfaced.

A.2 Descriptive Statistics

The summary statistics of the considered EU sovereign intra-day CDS data are presented in Table 5. We have split the data in 5 periods because within each of these five periods we have found similar statistical behavior. The first period covers the entire year 2009 and the second period starts in 2010 and ends on the 18.10.2011, when it became clear that the anticipated ban of uncovered sovereign CDS will become permanent. The third period ends in December 2012 and contains the discussion period on what the ban should look like in detail and the implementation of the ban. The fourth period starts in January 2013 and lasts until end of June 2014. This period contains the consultation period and announcement of the important changes on credit derivatives definitions and standard reference obligations, which became effective on the 22.09.2014 and which falls in our last period.

We report the mean, median and standard deviation as well as the mean bid-ask spread and the average number of observations. The mean and median reported in Table 5 are consistent with the time series plots in Figure 1. The standard deviation grows as expected with the mean/median. We furthermore measure the changes within a day relative to the changes from one day to the next by comparing mean absolute differences (MAD) in a ratio.[29] A ratio smaller than 1 shows that the data varies less within one day than across days. This is almost always the case, with exception of Germany, France and Ireland in 2013 and 2014. While we have almost no empty time-stamps in 2010-2012 we recognize that data availability slightly decreased in 2013 and more in 2014, which is reported in the average number of observations per day in Table 5.

We have also analyzed the first differences of CDS spreads and have found that the mean and the median of the first differences are around zero. The standard deviation is in the

[29] For robustness reasons, we consider averages of the first and second half of one day, which we denote by $\bar{d}_t^1$ and $\bar{d}_t^2$, respectively. Intra-day MAD is then computed by $\sum_{t\in T} |\bar{d}_t^2 - \bar{d}_t^1|$ and inter-day MAD is computed by $\sum_{t\in T} |\bar{d}_{t+1}^1 - \bar{d}_t^2|$. The ratio, intra-day MAD divided by inter-day MAD, shows how much the data varies within one day compared to across days.

Table 4: Crisis Related Events

The table reports dates connected to policy interventions which are analyzed in the main body of the paper. Considered key dates are marked in bold.

Issue	Date	Event
Greece I & SMP I (1 & 2)	23.04.10 Fri	official request for financial support from Greek government
	27.04.10 Tue	S&P downgrades Greece
	28.04.10 Wed	EU and IMF officials hold crunch talks with German leaders. Rumours of a €120bn package emerge
	02.05.10 Sun	Eurogroup agreed to provide bilateral loans
	03.05.10 Mon	MoU was signed and ECB announces that Greek bonds will be accepted as collateral no matter their rating
	05.05.10 Wed	S&P downgrades Greece
	10.05.10 Mon	SMP starts
Ireland (3)	21.11.10 Sun	official request for financial support from Irish government
	26.11.10 Fri	Eurogroup approves loan to Ireland
	28.11.10 Sun	Troika and Ireland agreed program
	30.11.10 Tue	detailed discussions ended, program finalized
	01.12.10 Wed	IMF approves loan to Ireland, MoU signed
Portugal (4)	07.04.11 Thu	official request for financial support from Portuguese government
	08.04.11 Fri	Eurogroup approves loan
	03.05.11 Tue	reaches deal for bailout
	05.05.11 Thu	program was announced by Portuguese authorities
	16.05.11 Mon	EU and Portuguese parliament approves bailout package
	20.05.11 Fri	IMF approves loan
Greece II & SMP II (5 & 6)	17.06.11 Fri	Merkel/Sarkozy - agreement on second bailout, private sector involvement
	20.07.11 Wed	Merkel/Sarkozy - meeting to develop common stance on 2nd bailout
	21.07.11 Thu	Euro Summit/EU - agreement on second bailout
	08.08.11 Mon	SMP second wave starts
Greek default (7)	01.03.12 Thu	ISDA declares no credit event for Greece
	09.03.12 Fri	ISDA declares credit event for Greece
Spain & Draghi speech (8 & 9)	09.06.12 Sun	emergency meeting Eurogroup regarding Spanish banks
	21.06.12 Thu	decision that 62bn euros will be shared among Spanish banks in need
	25.06.12 Mon	request for assistance by Spanish government
	20.07.12 Fri	Eurogroup agrees bailout
	23.07.12 Mon	MoU for Spanish bank bailout signed
	26.07.12 Thu	Draghi speech "... whatever it takes ..."
	06.09.12 Thu	OMT

Table 5: Summary statistics of intraday EU sovereign CDS spreads

The table presents the detailed descriptive statistics for five periods, for which we have found similar statistical behaviour of the CDS levels. The mean, median and standard deviation are reported, as well as the ratio of mean absolute difference (MAD) of intraday and inter-day level changes. Further, the mean of the bid-ask spread and the average number of observations per day is reported. No figures are shown for the last three periods for Greece because of the Greek restructuring.

		1.1.09-31.12.09	1.1.10-18.10.11	19.10.11-31.12.12	1.1.13-30.6.14	1.7.14-31.12.14
France	Mean	41.92	87.46	162.90	63.41	46.76
	Median	35.58	78.75	175.50	64.94	45.87
	Standard deviation	20.85	36.03	48.17	13.90	5.70
	MAD intra/inter ratio	0.38	0.17	0.20	1.47	1.59
	Mean bid-ask-spread	0.11	0.04	0.03	0.04	0.07
	Average obs/day	14.49	17.82	17.55	16.72	15.02
Germany	Mean	38.64	48.45	74.78	28.01	20.84
	Median	33.33	43.12	80.97	25.33	20.75
	Standard deviation	19.74	17.62	24.45	6.91	2.28
	MAD intra/inter ratio	0.38	0.22	0.24	2.01	2.09
	Mean bid-ask-spread	0.11	0.06	0.05	0.08	0.12
	Average obs/day	14.42	17.73	17.50	16.64	14.98
Greece	Mean	172.00	960.53			
	Median	154.16	863.06			
	Standard deviation	54.55	524.13			
	MAD intra/inter ratio	0.29	0.21			
	Mean bid-ask-spread	0.05	0.04			
	Average obs/day	15.18	17.64			
Ireland	Mean	203.06	476.85	521.62	128.42	55.52
	Median	184.33	537.35	575.89	136.83	54.50
	Standard deviation	65.34	247.53	186.00	41.72	5.21
	MAD intra/inter ratio	0.28	0.20	0.28	1.14	1.88
	Mean bid-ask-spread	0.05	0.04	0.05	0.07	0.11
	Average obs/day	15.18	17.87	17.44	16.86	15.14
Italy	Mean	108.72	202.93	422.43	204.81	115.88
	Median	94.75	177.62	437.55	229.50	111.00
	Standard deviation	40.86	94.67	94.21	61.33	20.32
	MAD intra/inter ratio	0.29	0.16	0.19	0.47	0.90
	Mean bid-ask-spread	0.05	0.03	0.02	0.02	0.04
	Average obs/day	15.23	17.86	17.59	17.35	15.67
Portugal	Mean	80.71	492.75	911.46	338.43	188.28
	Median	72.75	432.45	1033.13	362.50	191.83
	Standard deviation	28.54	294.02	284.25	107.28	23.79
	MAD intra/inter ratio	0.29	0.19	0.35	0.50	0.69
	Mean bid-ask-spread	0.06	0.04	0.06	0.04	0.07
	Average obs/day	14.86	17.87	16.75	17.03	15.36
Spain	Mean	93.68	245.05	429.43	191.06	83.07
	Median	87.70	238.50	405.88	214.60	78.00
	Standard deviation	27.37	80.80	92.10	71.86	17.07
	MAD intra/inter ratio	0.27	0.18	0.19	0.54	0.93
	Mean bid-ask-spread	0.05	0.03	0.02	0.03	0.06
	Average obs/day	15.04	17.87	17.60	17.31	15.69

order of one, with slightly larger values for the crisis countries. The standard deviation for Greece in the second period is largest.

Results on the unit root and stationarity tests are presented in Table 6 for levels and first differences. We conclude that all series are integrated of order one.

Table 6: Unit root and stationarity tests for CDS data - 2009-2014

The table reports the statistics of unit root and stationarity tests of the intraday CDS data. The null hypothesis of the ADF and PP test is: the data has a unit root. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

	levels			first differences		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.40	0.53	4.74	0.00	0.00	0.09
Germany	0.25	0.43	3.71	0.00	0.00	0.36
Greece	1.00	1.00	14.31	0.00	0.00	0.65
Ireland	0.76	0.77	5.21	0.00	0.00	0.25
Italy	0.48	0.35	6.23	0.00	0.00	0.17
Portugal	0.96	0.89	6.23	0.00	0.00	0.26
Spain	0.21	0.25	6.24	0.00	0.00	0.17

A.3 Generalized Variance Decomposition

Here we develop the main steps for the variance decomposition components from Equation (4) via the impulse response function.[30] Koop et al. (1996) define the generalized impulse response function $\mathbf{GI}$ of $\mathbf{y_t}$ at horizon H for a shock of size δ and a known history $\mathbf{\Omega}_{t-1}$ as follows:

$$\mathbf{GI}(H, \delta, \mathbf{\Omega}_{t-1}) = E(\mathbf{y}_{t+H}/\mathbf{u_t} = \delta, \mathbf{\Omega}_{t-1}) - E(\mathbf{y}_{t+H}/\mathbf{\Omega}_{t-1}). \tag{6}$$

For a shock only on the j-th element of $\mathbf{u_t}$, the function is written as:

$$\mathbf{GI}_j(H, \delta_j, \mathbf{\Omega}_{t-1}) = E(\mathbf{y}_{t+H}/\mathbf{u_{tj}} = \delta_j, \mathbf{\Omega}_{t-1}) - E(\mathbf{y}_{t+H}/\mathbf{\Omega}_{t-1}). \tag{7}$$

In this case, the effects of the other shocks must be integrated out. For $\mathbf{u}_t$ normally distributed we have:

$$E(\mathbf{u}_t/\mathbf{u}_{tj} = \delta_j) = (\sigma_{1j}, \sigma_{2j}, \cdots, \sigma_{nj})' \frac{\delta_j}{\sigma_{jj}} = \Sigma_u e_j \frac{\delta_j}{\sigma_{jj}}. \tag{8}$$

Thus, the generalized impulse response is given by

$$\mathbf{GI}_j(H, \delta_j, \mathbf{\Omega}_{t-1}) = \mathbf{\Phi}_H \Sigma_u e_j \frac{\delta_j}{\sigma_{jj}}. \tag{9}$$

[30] See Hamilton (1994) for the link between impulse responses and forecast error variance decomposition.

By setting $\delta_j = \sqrt{\sigma_{jj}}$ one obtains an impulse response function which measures the effect of one standard error shock to the jth variable at time t on the expected values of $\mathbf{y}$ at time $t+H$:

$$\mathbf{GI}_j(H, \delta_j, \mathbf{\Omega}_{t-1}) = \sigma_{jj}^{-1/2} \mathbf{\Phi}_H \Sigma_u e_j. \tag{10}$$

As in Pesaran and Shin (1998), this is used to derive the generalized forecast error variance decomposition components $s_{ij}(H)$ in Equation (4).

A.4 Liquidity Proxys

Figure 14 presents the full time evolution of the time-aggregated relative bid-ask spreads. Moreover, in Figure 15 we present volume data (left-hand side) and number of trade counts (right-hand side) as two additional measures of liquidity. Based on these figures, we do not find a dry-out of liquidity in the considered period 2009-2014.

Figure 14: Relative bid-ask spreads

The figure illustrates relative bid-ask spreads, defined as (ask price-bid price)/((ask price+bid price)/2) for the period 2008 until end 2014.

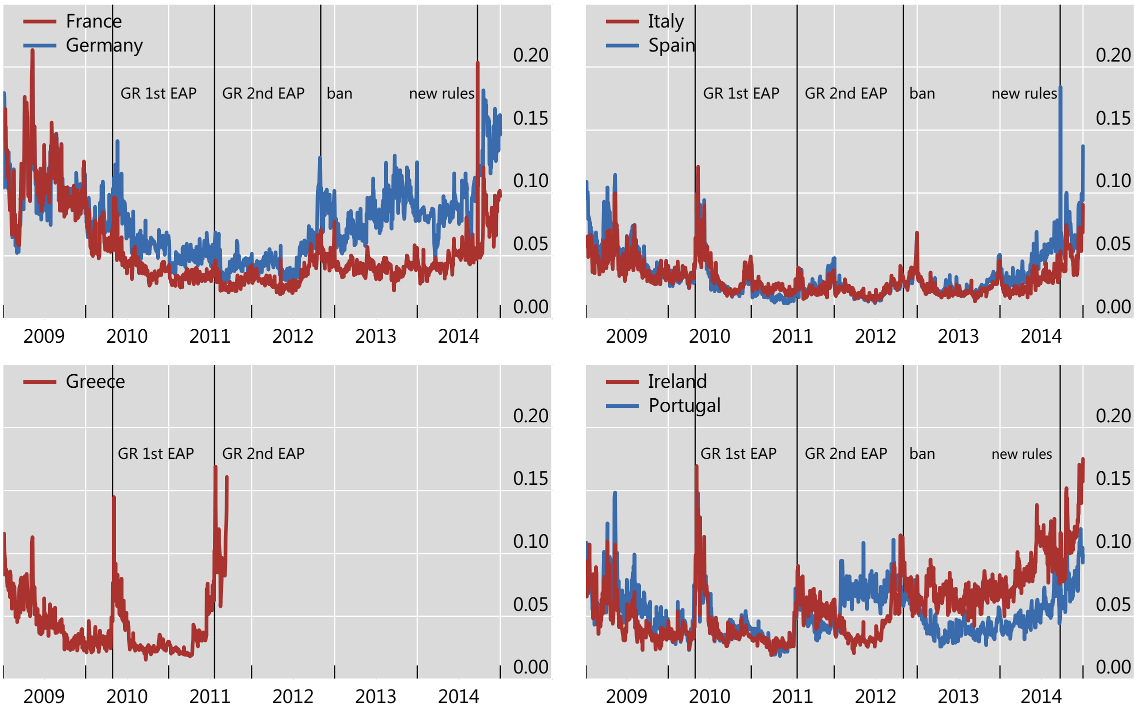
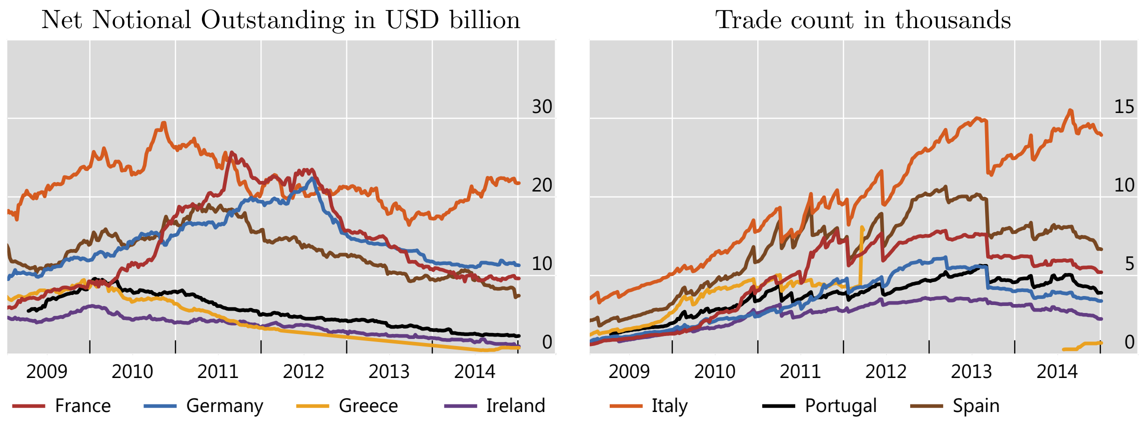


Figure 15: CDS trading volume and trade count

The figure illustrates net notional amounts outstanding (left-hand panel) and trade counts (right-hand panel), based on publicly available weekly data.



A.5 Table 1 - unshifted

Table 7: Intervention impact of regulatory measures

For each regulatory intervention I, we evaluate its impact by assessing spillovers before the respective starting action $I1$ and after the final implementation stage $I2$. The table presents time aggregates in mean with respective empirical standard deviations in parentheses of connectedness over a window of 200 observations before an intervention $\overline{I1-}$ or after $\overline{I2+}$. The p-value of the respective two-sample significance test for a constant spillover level in the time interval of $\overline{I1-}$ and $\overline{I2+}$ is reported as $p_{I1,I2}$. The intervention impact is measured as $\Delta_{I1,I2}$ marking the relative change $((\overline{I2+}) - (\overline{I1-}))/(\overline{I1-})$ in %. Results are reported for total (in bold) and country-wise connectedness based on CDS spreads. In the case of the ban, effects for total connectedness of bond yields are also reported as additional control in the line bonds. The labeling of events is as in Figure 2.

	Ban 2012: events A and C				**New CDS Rules 2014**: events D and E			
	$\overline{A-}$	$\overline{C+}$	$p_{A,C}$	$\Delta_{A,C}$	$\overline{D-}$	$\overline{E+}$	$p_{D,E}$	$\Delta_{D,E}$
total	**0.60**(0.03)	**0.38**(0.05)	**0.00**	**-36.67**	**0.54**(0.04)	**0.15**(0.03)	**0.00**	**-72.22**
DE	0.54(0.06)	0.27(0.07)	0.00	-50.00	0.45(0.04)	0.07(0.04)	0.00	-84.44
ES	0.77(0.05)	0.61(0.06)	0.00	-20.78	0.60(0.06)	0.16(0.07)	0.00	-73.33
IE	0.30(0.07)	0.26(0.09)	0.00	-13.33	0.57(0.09)	0.12(0.05)	0.00	-78.95
IT	0.73(0.03)	0.64(0.03)	0.00	-12.33	0.56(0.03)	0.12(0.03)	0.00	-78.57
FR	0.80(0.02)	0.31(0.05)	0.00	-61.25	0.45(0.07)	0.18(0.05)	0.00	-60.00
PT	0.48(0.04)	0.13(0.03)	0.00	-72.92	0.60(0.04)	0.25(0.07)	0.00	-58.33
bonds	**0.25**(0.06)	**0.24**(0.02)	**0.02**	**-4.00**				

A.6 Country-wise intervention impact of monetary policy actions

Table 8: Constant country-wise intervention impact of monetary policy actions

For each monetary policy intervention I, we evaluate its impact by assessing spillovers right before the action and afterwards. For events which happen in close succession we investigate the combined effects. For more details we refer to Table 7. The numbering I of events in the first column is as in Figure 2.

		Country-wise Connectedness				Country-wise CDS			
I		$\overline{I-}$	$\overline{I+}$	p_I	Δ_I	$\overline{I-}$	$\overline{I+}$	p_I	Δ_I
GR1 EAP& SMP1 (1 & 2)	DE	0.32(0.07)	0.61(0.07)	0.00	90.62	43.01(5.96)	46.58(1.47)	0.00	8.30
	ES	0.76(0.07)	0.91(0.03)	0.00	19.74	179.52(7.74)	160.78(13.15)	0.00	-10.44
	FR	0.32(0.07)	0.69(0.07)	0.00	115.62	64.93(5.67)	65.69(3.50)	0.28	1.17
	GR	0.56(0.09)	0.67(0.10)	0.00	19.64	622.27(101.47)	529.82(37.53)	0.00	-14.86
	IE	0.49(0.08)	0.70(0.06)	0.00	42.86	190.18(31.52)	176.21(12.09)	0.00	-7.35
	IT	0.75(0.09)	0.69(0.08)	0.00	-8.00	142.09(8.81)	138.41(10.00)	0.01	-2.59
	PT	0.77(0.10)	0.71(0.04)	0.00	-7.79	291.26(49.79)	225.5(24.46)	0.00	-22.58
IE EAP (3)	DE	0.45(0.11)	0.38(0.09)	0.00	-15.56	46.87(6.19)	48.2(2.35)	0.06	2.84
	ES	0.77(0.05)	0.66(0.13)	0.00	-14.29	326.43(30.54)	310.94(14.79)	0.00	-4.75
	FR	0.56(0.11)	0.62(0.13)	0.00	10.71	94.03(7.55)	93.63(2.89)	0.64	-0.43
	GR	0.39(0.06)	0.51(0.06)	0.00	30.77	968.84(23.47)	904.49(14.16)	0.00	-6.64
	IE	0.57(0.05)	0.61(0.11)	0.00	7.02	592.68(22.11)	554.23(13.12)	0.00	-6.49
	IT	0.67(0.05)	0.67(0.04)	0.86	0.00	223.21(27.57)	220.52(11.58)	0.40	-1.21
	PT	0.71(0.07)	0.56(0.13)	0.00	-21.13	513.01(34.38)	451.07(26.74)	0.00	-12.07
PT EAP (4)	DE	0.23(0.08)	0.43(0.07)	0.00	86.96	44.04(1.03)	40.21(0.73)	0.00	-8.70
	ES	0.83(0.07)	0.91(0.02)	0.00	9.64	245.81(9.06)	242.52(10.87)	0.03	-1.34
	FR	0.38(0.14)	0.68(0.04)	0.00	78.95	76.64(2.36)	75.36(2.39)	0.00	-1.67
	GR	0.52(0.11)	0.62(0.10)	0.00	19.23	1327.61(25.99)	1312.39(29.14)	0.00	-1.15
	IE	0.46(0.08)	0.64(0.06)	0.00	39.13	664.97(10.90)	657.87(15.82)	0.00	-1.07
	IT	0.78(0.10)	0.92(0.02)	0.00	17.95	151.57(5.33)	152.13(7.70)	0.58	0.37
	PT	0.61(0.08)	0.81(0.02)	0.00	32.79	661.55(13.21)	636.76(13.35)	0.00	-3.75
GR2 EAP& SMP2 (5 & 6)	DE	0.54(0.13)	0.67(0.05)	0.00	24.07	59.84(3.16)	82.41(3.83)	0.00	37.72
	ES	0.82(0.04)	0.81(0.03)	0.00	-1.22	347.25(20.22)	361.95(19.05)	0.00	4.23
	FR	0.83(0.08)	0.73(0.10)	0.00	-12.05	110.79(8.14)	162.68(9.37)	0.00	46.84
	GR	0.42(0.23)	0.15(0.05)	0.00	-64.29	2395.57(155.75)	1709.78(51.18)	0.00	-28.63
	IE	0.71(0.07)	0.55(0.09)	0.00	-22.54	1106.18(82.31)	764.41(25.8)	0.00	-30.90
	IT	0.90(0.03)	0.80(0.08)	0.00	-11.11	296.64(22.32)	357.19(20.93)	0.00	20.41
	PT	0.62(0.06)	0.51(0.05)	0.00	-17.74	1127.44(74.94)	866.99(24.07)	0.00	-23.10
ES EAP& Draghi (8 & 9)	DE	0.39(0.04)	0.39(0.09)	0.70	0.00	75.97(2.55)	72.01(2.61)	0.00	-5.21
	ES	0.65(0.03)	0.48(0.11)	0.00	-26.15	572.6(14.17)	546.68(20.70)	0.00	-4.53
	FR	0.57(0.04)	0.50(0.05)	0.00	-12.28	164.73(4.19)	162.46(5.64)	0.00	-1.38
	IE	0.36(0.05)	0.29(0.06)	0.00	-19.44	548.24(7.65)	518.69(16.89)	0.00	-5.39
	IT	0.72(0.03)	0.62(0.07)	0.00	-13.89	505.97(7.95)	494.02(15.18)	0.00	-2.36
	PT	0.06(0.03)	0.15(0.04)	0.00	150.00	839.13(8.33)	852.35(19.91)	0.00	1.58

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