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Regulatory changes and long-run relationships of the EMU sovereign debt markets: Implications for future policy framework

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ABSTRACT

We estimate the time-varying long-run correlations of European sovereign bond markets to identify specific effects that are attributed to changing European regulatory and political dynamics over the last twenty years. Our empirical results from using the DCC-MIDAS methodology indicate that regulatory changes in Europe have created significant and negative impact on the long-run correlations within the month where the regulation is decided to be taken into action. This impact still remains in the following months and robust with respect to the trend component of the long-run correlations. A direct implication is that the more regulations the EU attempts to put in place, the lower the long-run convergence process of sovereign bond markets is. We then analyse the structural shifts in the long-run correlation dynamics with penalized contrasts methodology and try to find out the reasons of these severe changes. Accordingly, some of the structural shifts overlap with the dates of a limited number of regulatory changes, in addition to the major global economic and political events.

1. Introduction

The European Union has witnessed substantial structural, regulatory and political changes in the past twenty years since the introduction of the euro. Much research has focused on the development of a broad convergence in the yields of European bonds after the development of a strong monetary union (Codogno et al., 2003; Kim et al., 2006; Christiansen, 2007). This is particularly important due to the broad diversification effects that existed through the creation of such a cohort of sovereign states, each offering quite unique strengths and skills to the union, with the smallest countries seeking added economic security through diversification, shared skills, experiences, financing sources, and the reinforced bargaining strength that was provided through such a large number of countries when negotiating international trade agreements. However, these countries also incorporated broad structural issues towards the European Monetary Union (EMU), manifesting in what can only be described as one of the worst sovereign debt crises taking place in countries such as Greece, Ireland, Portugal, Italy, Cyprus and Spain. Among these countries, both Greece and Ireland necessitated third-party financial support and intervention due to the deep-rooted nature of their sovereign banking crises.[1] The development of the EMU has also withdrawn both monetary and many

[1] Specifically focusing on the Irish economic collapse, Corbet (2016) discusses the broad regulatory deficiency that existed in Ireland during the generation of the 'Celtic Tiger,' a period synonymous with the rapid expansion of the Irish economy, where the actions of its regulators and policy makers undoubtedly generated not only a catalyst to financial ruin, but also an incubator to strengthen its severity. Banks were found to be firmly leveraged towards the Irish property market and the role of leverage in financial markets created mispricing, to which the basic principles of

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fiscal policy options as tools through which the crisis can be mitigated and alleviated. This was evident in the economic collapse of the countries denoted as 'PIIGS' as monetary policy had to be tailored to the needs of the EMU rather than the needs of specific nations.

The regulatory responses made by the European Union have been quite strong in the post-crisis era. Following the outbreak of the financial crisis, European regulatory reforms have focused on four key areas: (1) the strengthening of financial supervision; (2) the creation of tools to support bank recovery and resolution; (3) the creation of a more effective deposit protection system; and (4) the creation of an improved regulatory framework for banks, insurance companies, securities markets and other sectors. We must focus on analysing as to how these reforms have made the financial system more stable and resilient and as to whether they have influenced the perceptions of bond traders as measured by the yields of sovereign debt. Such regulatory restructuring necessitates re-evaluation of the many ways in which European corporations interact, particularly cross-border entities that are part of the same institution. Such reforms introduced after the crisis also need to be monitored to check whether they are delivering intended outcomes and to assess whether the new rules have any unintended consequences. Appendix A provides a detailed overview of the key completed reforms that have been introduced along with the rationale supporting their introduction.

Some of the earliest commissioned and now completed financial reforms include those related to the risk-based prudential and solvency rules for insurers (Solvency II), AIFMD, CRD III, the establishment of the European Supervisory Authority, deposit guarantee schemes, derivative reform through EMIR, the creation of the Single Euro Payments Area (SEPA), MIFID, and a wide range of market abuse and transparency reforms among others.[2] The European Commission developed such reforms through the establishment of a number of policy advising expert groups,[3] representing consultative bodies set up by the Commission to provide advices in relation to the preparation of legislative acts and policy initiatives usually composed of experts appointed by EU governments.

As far as the sovereign debt crisis is concerned, a common wisdom is that the regulatory changes affect the dynamics of sovereign risks and the ways the sovereign bond markets co-move over time. In this paper, we give a close look to this issue by considering a broad range of the European regulatory reforms as potential sources of changing time-varying bond market behaviour. We also devote our attention to some of the many significant political events that have occurred during the past twenty years in Europe as political developments in the European Union, which have been particularly extraordinary in more recent times, play a pivotal role on regulations. Corbet and Larkin (2018) briefly review these political shifts and show that the latter have developed within the widespread financial crises and been exacerbated in some states by the dramatic influx of illegal immigration. As a result, Europe finds itself at a crossroads inspired by political spectrum shifts to the left and the right, with fear, uncertainty fuelling nationalist revolt across a host of European nations. Such political shifts have also manifested in the nationalist-based decision-making resulting in the growth of right-based decisions such as the Brexit or the Italian budgetary issues witnessed in recent years. Much evidence has been provided that contagion effects exists in such political decision-making (Mei and Guo, 2004; Rajsingh, 2016). It is thus opportune to identify as to whether such political developments are a source of instability for time-varying sovereign debt instability, with further emphasis on the presence of contagion effects.

One of the key data through which we can identify both the severity and contagion effects of crises is through sovereign bond yields. Our research shifts attention to the long-run relationship of sovereign bond markets, instead of their divergence since the rapid development of both the European regulatory and political environments. In particular, our methodological choice focuses on the inherent time variations in such structural destabilizations, i.e., as to whether European sovereign bond markets experience long-term structural destabilization in the aftermath of changes in the regulatory and political environments. This builds on the work of Colacito et al. (2011) who introduced the DCC-MIDAS methodology to analyse the long-run correlation components between financial time series. According to our perspective, while political instability has quite strong theoretical grounding for producing influence on sovereign bond markets, it is very important to further understand as to whether financial markets themselves were in agreement with the European Central Bank's views that its regulatory actions were in fact fostering the resilient and sustainable development of Europe's financial landscape. Within this context, such regulatory intervention might be observed as beneficial to financial stability, but could also be detrimental to sectoral and regional profitability, growth and development.

According to our analysis, we contribute to the literature by showing that the regulatory changes in Europe have significant and negative impact on the long-run correlations of the sovereign bond markets of the major eurozone countries. These correlations also change drastically within the month where the regulation is implemented and this change is preserved within the following months, showing that effects of regulatory changes in the EU are not transitory and do sustain on the correlation dynamics of these sovereign bond markets. We check whether this finding is distorted by the trend components of the long-run correlations or not, and reveal that the results are robust. A direct implication and one of the main contributions of the paper is the finding that the more regulations the EU attempts to put in place, the lower the long-run convergence process of sovereign bond markets is. Next and as a robustness check, we focus on detecting potential structural shifts in the long-run correlations and examining whether they are associated with regulatory changes. By applying the penalized contrasts methodology of Lavielle (2005) to detect the change points, we show that the structural shifts in the long-run correlations occur around the times when major regulatory changes or important political events take place (such as the critical stages of the Brexit process), supporting our view that both political uncertainties and regulatory actions are drivers of the long-run relationship between the sovereign bonds of major eurozone member countries.

The rest of the paper is organized as follows. Section 2 presents a concise review of the literature based on sovereign bond dynamics, structural changes in European regulatory dynamics and the influence of broad political events on financial markets. We provide a brief review of the DCC-MIDAS methodology in Section 3. Section 4 reports the data that we use and the corresponding empir-

the efficient market hypothesis (EMH) failed. This miscalculation of risk was severe and destructive for the real economy.

[2] We must note that there are a wide-range of actions that have been established but have not yet been completed. These include a number of structural reforms on banks, the creation of the European deposit insurance scheme (EDIS), rules on capital requirements, the development of a EU framework on covered bonds, addressing risks related to NPLs, insurance companies and sovereign bond-backed securities, and the strengthening of bank recovery and resolution (BRRD) among others. A summary of these development can be found in Appendix B.

[3] The key financial regulation groups established in accordance with Declaration 39 on Article 290 of the Lisbon Treaty include the expert groups on Banking, Payments and Insurance; Sustainable Finance; Corporate Bond Market Liquidity; Cross-border redress in financial services; Derivatives and Market Infrastructures Member States; European Crowdfunding Stakeholders Forum; European Post Trade Forum; the European Securities Committee; the Expert Group on barriers to free movement of capital; intra-EU cross border investment environment; the evaluation of the IAS Regulation; Retail Financial Services; Mortgage Credit; the Group of representatives of financial services employees (UNI Europa); the Payment Systems; and the Securities Law Directive Member States Working Group.

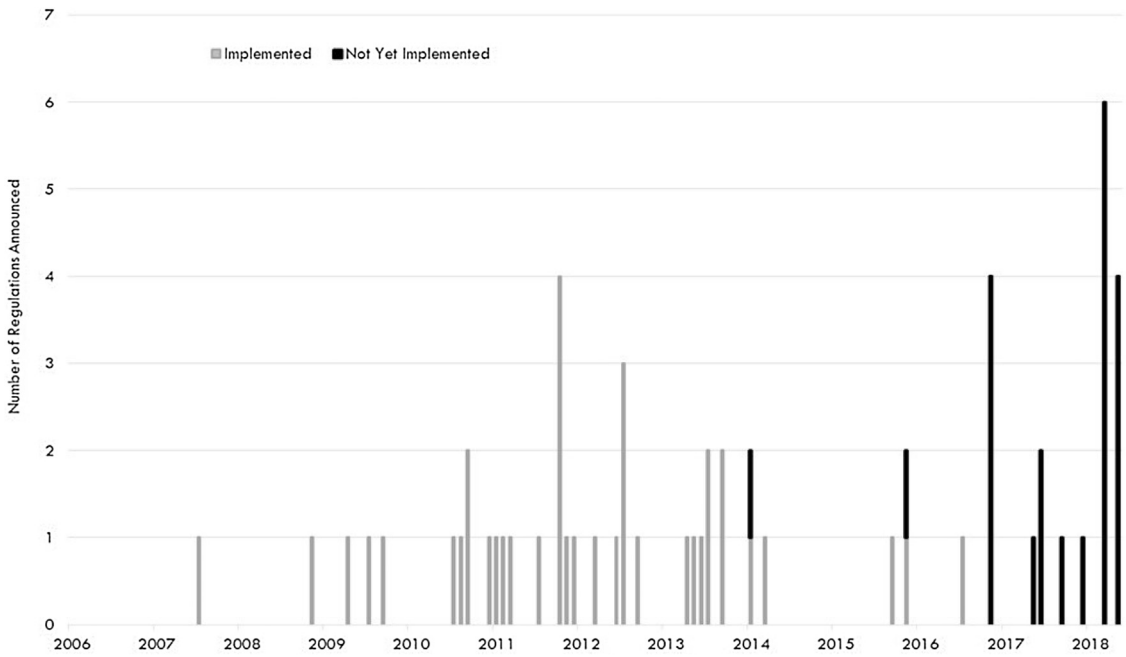

Fig. 1. Fully and partially implemented regulatory changes in Europe, 2006–2018. Note: The above data represents all proposals of financial reform that are finalized-implemented or being planned by the European Commission. Data available at https://ec.europa.eu.

ical results. Section 5 provides some discussions and concluding remarks.

2. Literature review

The European response to the international financial crises has generated a broad range of both anticipated and unanticipated consequences for multiple sovereign states across a range of both economic and political environments. Within this section, we provide a thorough overview of the key dynamics that have been observed within European sovereign debt markets, which further suggests the key identified drivers of instability sourced within economic and political drivers of bond market volatility and contagion.

Kim et al. (2006) were among the first researchers that empirically investigate the influence of the EMU on time variations in inter-stock-bond market integration/segmentation dynamics to find that real economic integration and the reduction of currency-market risk supported financial integration, but in fact generated a flight-to-safety effect due to broad fears about the future of the EMU. Christiansen (2007) echoed such evidence of EMU integration in the period after the introduction of the euro with the key driver identified to be that of interest rates. Corbet (2014) found that European sovereign downgrades are found to be associated with an increase in equity returns and cause significant increases in the cost of insuring debt through CDS and the yield of government debt. In a recent study, Sensoy et al. (2019) uncovered a high degree of sovereign debt market integration between the EMU members over the period preceding the recent financial crises, while segmentation is found afterwards. However, the Fed's tapering policy announcement in 2013 generated an impact towards an integration of these markets again.

Bessembinder et al. (2006) found that changes in market designs through regulations can have first-order effects on trade execution costs on bonds even for sophisticated institutional investors. Heathcote and Perri (2002) found that the financial autarky model can generate volatility in the terms of trade when constructing a two-country, two-good model, to account for observed cross-country output, consumption, investment and employment correlations. Such a result identified that international capital flows are exceptionally important for the international business cycle. The creation of the EMU would have greatly increased this effect.

The severity of the 2008–2009 global financial crisis and the European sovereign debt crisis that followed was widely observed as a critical point in the sharp changes in regulatory dynamics that followed in Europe. This is obvious in Fig. 1 which presents evidence of the timeline of introduction of regulatory changes in Europe, while further considering the announcement of regulatory changes that have not been implemented yet. Mohl and Sondermann (2013) found that statements about restructuring, bailout and the involvement of the European Financial Stability Facility (EFSF) have impacted bond spreads of countries in the periphery over Germany, indicating that the more different euro area governments issued statements at the same time, the more bond spreads have increased. Furthermore, the authors find that statements from politicians from AAA-rated countries seemed to have a particularly strong impact on spreads. Lierse and Seelkopf (2016) found that in the context of financial market pressures in the form of rising bond yields, European governments raised their taxes, especially in the more regressive field of indirect taxes, suggesting that capitalist democracies have little political room to maneuver and to conduct redistributive politics at times of high fiscal stress. Katsikas (2011) found that the EU's decisions to adopt the standards produced by the International Accounting Standards Board (IASB), and to establish a new, differentiated European accounting regulatory mechanism, were driven by its desire to bolster European influence.

De Grauwe et al. (2017) found evidence that a significant part of the surge in the sovereign bond spreads of the peripheral Eurozone countries was determined from a broad disconnection from underlying fundamentals and particularly from a country's debt position. This was found to be more likely to be associated with market sentiments and liquidity concerns. But long-term political changes have also manifested in the incredible economic events that had taken place in countries such as Cyprus and Italy (Michaelides, 2014; Deeg, 2005). Benediktsdottir et al. (2011) found that Icelandic authorities as a matter of policy encouraged the creation

of an international banking centre, involving the privatization and deregulation of the banking system, rules and regulations being relaxed and the neglect of financial supervision. This inevitably reduced sovereign financial diversification.

Mugge (2011) found that three key results were evident after the EU had taken a role in global financial governance. First, the EU has stabilized, rather than challenged. Second, the EU continues to be one of two central nodes in GFG, which essentially still is a transatlantic affair, confounding expectations that Europe would find itself in a much more dispersed web of links with other regulatory powers around the world. Third, given its special institutional character, there are signs that a prominent EU may transform governance, but it still remains unclear how pronounced these dynamics will be.

Corbet and Larkin (2017) found that European countries with more local banking networks in the form of credit unions, public banks or savings banks, generate greater levels of volatility when compared to that of their commercial counterparts, particularly in countries with more monopolistic sectors. Further, the announcements of the European Banking Authority generate significant volatility effects for the European banking sector at large, with particular emphasis on stress testing results, but also announcements based on recapitalization, regulation and transparency. The results indicate that uniformity of regulation may in fact be hindering and restricting the growth of some domestic and more peripheral and locally designed banking sectors in the form of rules designed for commercial banking operations.

Regarding our methodology, several studies have used the DCC-MIDAS technique to investigate the interactions between EMU markets. The DCC-MIDAS mainly differs from standard GARCH-family models as it allows a baseline variance to vary slowly throughout the time period analysed. Virk and Javed (2017) focused specifically on European stock markets between 1990 and 2013 using DCC-MIDAS to identify evidence of substantial divergence from Greek risk during the European financial crisis period. In particular, cross-country joint relationships of conditional variance and return correlations are found to be typically positive. Boffelli et al. (2016) focused on both the high and low frequency correlations in European government bonds via DCC-MIDAS while considering their economic drivers. They find strong links between spreads' volatility and worsening macroeconomic fundamentals. Accordingly, relative spreads move together in presence of similar macroeconomic fundamentals; yet the increasing correlation in spreads during the burst of the sovereign debt crisis cannot be entirely ascribed to macroeconomic factors but rather to changes in market liquidity. Nitoi and Pochea (2019) analysed the co-movements and contagion in 24 European Union stock markets from 2004 to 2016 using the DCC-MIDAS methodology and employ a gravity-type regression to investigate the determinants of long-term correlations. They obtained mixed findings for long-term correlations' drivers in contagion times, revealing a pure contagion that is not explained by fundamentals and a wake-up call in terms of cross-border bank flows.

3. Methodology

As stated in the introduction section, the major goal of this paper is to examine the impact of regulatory changes on the structural interdependencies of EMU sovereign bond markets as well as to discuss its implications for the future of regulations. We empirically proxy the structural interdependencies of these markets by their long-run dynamic yield correlations which will be obtained by the DCC-MIDAS methodology (Colacito et al., 2011).

Consider a set of n sovereign bonds and let the vector of daily changes in their yields be denoted by $r_t = [r_{1,t}, \ldots, r_{n,t}]'$ obeying the following process:

$$\begin{aligned} r_t &\sim_{i.i.d.} N(\mu, H_t) \\ H_t &= D_t R_t D_t \end{aligned} \tag{1}$$

where μ is the vector of unconditional means, H_t is the conditional covariance matrix and D_t is a diagonal matrix with standard deviations on the diagonal, and

$$\begin{aligned} R_t &= E_{t-1}[\xi_t \xi'_t] \\ \xi_t &= D_t^{-1}(r_t - \mu) \end{aligned} \tag{2}$$

The model above is estimated in two consecutive steps: (i) the conditional volatilities in D_t are estimated, and (ii) the conditional correlation matrix R_t is obtained.

3.1. GARCH-MIDAS estimation

We start with the work of Engle et al. (2013) who propose to separate volatility dynamics into short- and long-term components. This structure uses a mean-reverting unit daily GARCH process similar to Engle and Rangel (2008), and a MIDAS polynomial which applies to lower frequency variables.

We denote the short- and long-run variance components for bond i by g_i and m_i respectively. We keep long-run component m_i constant across the days of the low frequency period. N_v^i denotes the number of days that we hold m_i fixed. The two letters t and τ denote time-scales. In particular, $g_{i,t}$ moves daily whereas $m_{i,\tau}$ only once every N_v^i days.

We assume that for each bond i, univariate daily yield changes follow the GARCH-MIDAS process with two variance components:

$$r_{i,t} = \mu_i + \sqrt{m_{i,\tau} \times g_{i,t}}\xi_{i,t} \quad \text{where} \quad t = (\tau - 1)N_v^i + 1, \ldots, \tau N_v^i \tag{3}$$

The short-run variance component of returns follows a simple mean-reverting unit GARCH(1,1) process:

$$g_{i,t} = (1 - \alpha_i - \beta_i) + \alpha_i \frac{(r_{i,t-1} - \mu_i)^2}{m_{i,\tau}} + \beta_i g_{i,t-1} \tag{4}$$

with $\alpha_i > 0$, $\beta_i \geq 0$ and $\alpha_i + \beta_i < 1$ for stationarity. The short-run component $g_{i,t}$ accounts for daily fluctuations that are assumed short-lived, i.e., it relates to day-to-day concerns.

The low frequency component $m_{i,\tau}$ is a weighted sum of K_v^i lags of realized variances (RV) over a long horizon:

$$m_{i,\tau} = \overline{m}_i + \theta_i \sum_{l=1}^{K_v^i} \varphi_l(\omega_v^i) RV_{i,\tau-l} \tag{5}$$

where $\overline{m}_i$ and θ_i are free parameters to be estimated with $\overline{m}_i > 0$ and $0 \leq \theta_i < 1$ to guarantee a covariance stationary process. The $m_{i,\tau}$ is a trend component and relates to the effects of future expected global/macro-economic variables on volatility.

While setting N_v^i equal to the number of trading days within a month, the realized variances involve N_v^i daily non-overlapping squared returns as follows:

$$RV_{i,\tau} = \sum_{t=(\tau-1)N_v^i+1}^{\tau N_v^i} (r_{i,t})^2 \tag{6}$$

As a weighting function, we use a beta function with decay parameter ω_v^i:

$$\varphi_l(\omega_v^i) = \frac{(1 - \frac{l}{K_v^i})^{\omega_v^i - 1}}{\sum_{j=1}^{K_v^i}(1 - \frac{j}{K_v^i})^{\omega_v^i - 1}} \tag{7}$$

where the weight attached to past realized variances will depend on two parameters ω_v^i and K_v^i. For all $\omega_v > 1$, the weighting scheme

guarantees a decaying pattern, where the rate of decay is determined by the size of ω_v. Large (small) values of ω_v generate a rapidly (slowly) decaying pattern. By construction, $\varphi_l(\omega_v)$ are non-negative and sum to one.

3.2. DCC-MIDAS

In this step, we calculate the correlations based on the volatility adjusted (standardized) residuals $\xi_{i,t}$ obtained in Section 3.1:

$$\begin{aligned} q_{ij,t} &= \bar{\rho}_{ij,\tau}(1-a-b) + a\xi_{i,t-1}\xi_{j,t-1} + bq_{ij,t-1} \\ \bar{\rho}_{ij,\tau} &= \sum_{l=1}^{K_c^{ij}} \varphi_l(\omega_c) c_{ij,\tau-l} \\ c_{ij,\tau} &= \frac{\sum_{k=(\tau-1)N_c^{ij}+1}^{\tau N_c^{ij}} \xi_{i,k}\xi_{j,k}}{\sqrt{\sum_{k=(\tau-1)N_c^{ij}+1}^{\tau N_c^{ij}} \xi_{i,k}^2} \sqrt{\sum_{k=(\tau-1)N_c^{ij}+1}^{\tau N_c^{ij}} \xi_{j,k}^2}} \end{aligned} \tag{8}$$

where a and b are the driving parameters of the correlation process with $a, b > 0$ and $a + b < 1$ for stationarity; and the weighting scheme $\varphi_l(\omega_c)$ for correlations is similar to that one used in Eq. (7). As in the GARCH-MIDAS equation, the long-run (slowly moving) correlation $\bar{\rho}_{ij,\tau}$ does not vary at daily frequency t but at a lower frequency τ, and it is a weighted sum of K_c^{ij} lags of realized correlations (i.e., K_c^{ij} are span lengths of historical correlations), calculated on N_c^{ij} daily non-overlapping returns (i.e., N_c^{ij} are the lag lengths). Whereas, the daily conditional correlations between sovereign bonds i and j can easily be calculated by using time varying covariances $q_{ij,t}$ as shown by Engle (2002), i.e.,

$$\rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t}}\sqrt{q_{jj,t}}} \tag{9}$$

This two-component structure allows us to observe the short (ρ) and long ($\bar{\rho}$) run dynamics of the correlations. The parameters of the DCC-MIDAS are estimated by maximizing the following quasi-likelihood function

$$\begin{aligned} QL \quad &= -\sum_{t=1}^{T} (n\log(2\pi) + 2\log|D_t| + r_t' D_t^{-2} r_t) \\ &\quad - \sum_{t=1}^{T} (\log|R_t| + \xi_t' R_t^{-1} \xi_t + \xi_t'\xi_t) \end{aligned} \tag{10}$$

The first sum in Eq. (10) contains the data and the variance parameters (coming from GARCH-MIDAS estimation) while the second sum is based on volatility adjusted residuals and the correlation parameters.

4. Data and results

4.1. Sample data

We use daily 10-year benchmark sovereign bond yields for a sample of eleven countries in our analysis.[4] Sample countries are the major and also the earliest eurozone members; Austria, Belgium, Finland, France, Germany, Greece, Italy, Ireland, Netherlands, Portugal, and Spain. The data is obtained from Thomson Reuters Datastream and it covers a time period from January 4, 1999 (the introduction of euro) until May 28, 2019, which specifically includes the various phases of financial linkages in the European sovereign bond markets over the last 20 years.

Fig. 2 shows the changes in sovereign bond yields of the selected countries over the sample period. We observe a clear convergence of yields with the introduction of euro where this convergence keeps its pattern until the beginning of the European sovereign debt crisis in 2009. In particular, with a sharp increase in its sovereign bond yield, Greece demonstrates phases of divergence from the rest. In the following period, a similar divergence is also observed between the yields of the countries that struggle with debt (Ireland, Italy, Portugal and Spain) and those that are viewed as safe haven (France and Germany), suggesting a period of flight-to-quality by investors in these markets.

Table 1 presents the descriptive statistics of the daily changes (taken as the difference in yields in consecutive days), as well as the stationarity test results. We can see that all yields have a negative daily average change showing that cost of borrowing has decreased for all the sample countries in our study period. Greece has the lowest daily average (−0.0007) as expected due to the sustained periods of high yields, especially during the 2011–2012 sovereign bond crisis phase. For the same reason, it also has the highest yield increase (3.947) in a single day.

The unconditional volatility of the Greek sovereign bond yields (0.54), measured by standard deviations, is almost four times of Portugal (0.15), the country having the next highest bond yield volatility. Yield change distributions are skewed to the right except for the Greece, Italy, Ireland and Spain. Also, all yield changes exhibit excess kurtosis (fat tails), with Greece having an outstanding value of 660. Clearly, skewness and kurtosis coefficients indicate that return series are far from normally distributed. This departure from normality is confirmed by the Jarque–Bera test statistics that rejects normality at the 1% level for all series.[5]

Table 1 also presents the unit root test result for the stationarity of our daily change series (unit root tests contain a constant). Augmented Dickey–Fuller (ADF) test rejects the null hypothesis of unit root for all the series under consideration at the 1% significance level, indicating that all the daily yield change series are stationary.

4.2. Dynamics of short- and long-run correlations

The top panel of Table 2 displays the estimation results for the conditional yield change variances where the values in the parentheses below are the standard errors of the estimated coefficient. Accordingly, most of the parameters are significant at the 1% level. The sums of α and β vary within the range limited by 0.77 and 0.999 from below and above respectively, therefore satisfying the stationarity boundary $\alpha + \beta < 1$.

The decay parameter ω^v is substantially larger than 1 for majority of the bonds, indicating that weight of the lags decreases rapidly when calculating realized variances. On the other hand, this parameter is almost 1 for Austria, France and Germany, implying a flat weighting function for these countries. Estimation results for the MIDAS correlations are provided in the lower panel. The decay parameter ω_c implies a moderate level of decreasing weighting function. The a and b parameters are both highly significant, and their sum of 0.995 which is very close to 1, suggesting a long-run correlation with a highly persistent structure.

In our work, there are 11 countries under consideration, which makes the bilateral analysis impractical since we would have to analyse 55 different correlation structures. Instead, we proceed as follows. For each day, we take the equally weighted average of the daily yield changes of the sample sovereign bonds. This time series

[4] All the analysis in this work is performed by MATLAB.

[5] In the tables throughout this paper, *, ** and *** denote significance at the 10%, 5% and 1% levels respectively.

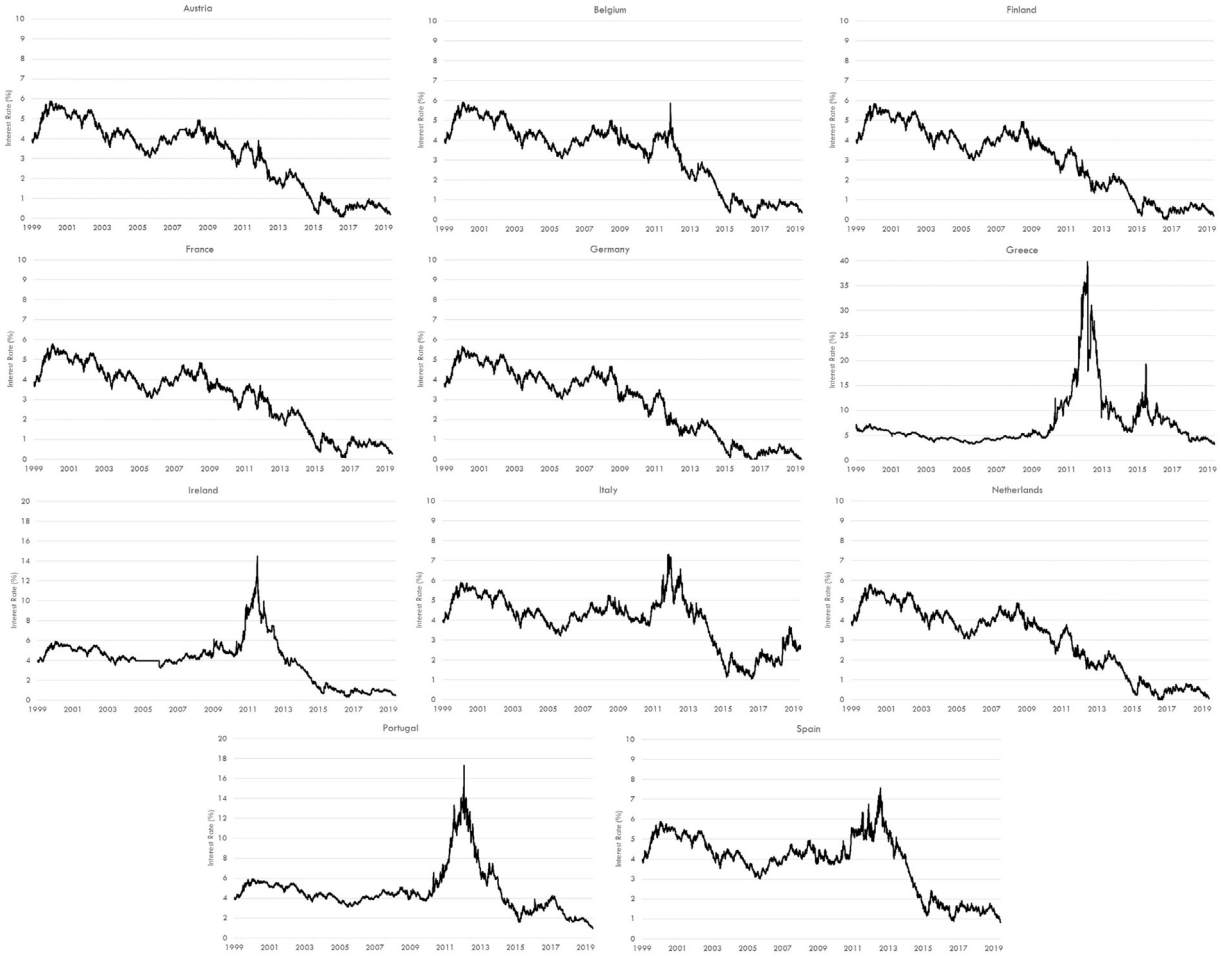

Fig. 2. European Sovereign Bond Yields from 1999 to 201.

Table 1
Summary statistics and results of unit root tests for the first differences in EMU sovereign bond yields.

	Mean	Max	Min	Std. Dev.	Kurtosis	Skewness	Jarque–Bera	ADF
Austria	−0.0017	0.3010	−0.2660	0.0454	7.7688	0.5289	2829.4***	−52.1***
Belgium	−0.0016	0.3710	−0.4290	0.0484	10.4977	0.2231	6689.9***	−45.7***
Finland	−0.0017	0.3240	−0.3700	0.0487	8.3430	0.0045	3385.3***	−58.2***
France	−0.0016	0.2470	−0.2160	0.0436	5.6112	0.1473	818.9***	−51.4***
Germany	−0.0017	0.2120	−0.2940	0.0444	5.2394	0.0806	597.8***	−51.7***
Greece	−0.0007	3.9470	−19.9140	0.5408	660.7464	−17.6632	$5 \times 10^{8***}$	−51.8***
Italy	−0.0009	0.5790	−0.8110	0.0713	15.2995	−0.1183	17,945.6***	−47.8***
Ireland	−0.0016	0.9230	−1.1730	0.0957	32.0463	−0.0354	$1 \times 10^{6***}$	−46.4***
Netherlands	−0.0017	0.1840	−0.2650	0.0420	5.0150	0.1613	493.8***	−51.7***
Portugal	−0.0015	2.0760	−1.6800	0.1468	55.8528	1.3621	$3 \times 10^{6***}$	−48.5***
Spain	−0.0014	0.6000	−0.9050	0.0737	19.6703	−0.6428	33,150***	−47.0***
Bechmark	−0.0015	0.3960	−1.8195	0.0662	210.4513	−7.4571	5,129,733.2***	−49.5***

Notes: Asymptotic critical values for the ADF test are −3.43, −2.86 and −2.57 for 1%, 5% and 10% significance levels respectively. We use the standard acronyms in the column tables for the country name abbreviations. In the last column, Benchmark refers to the cross-sectional equally-weighted daily yield changes of all sample sovereign bonds.

is called the benchmark. For each sample country, we analyse the relationship between the country itself and the aggregate market (benchmark series). This step reduces our analysis to only 11 correlation structures and it also helps us focus on the interaction with the overall market.

The long- and short-run correlation components between individual sovereign bond yields and the aggregate market yield are presented in Fig. 3. The different behaviours of the two components actually show how useful DCC-MIDAS models can be in understanding the structural changes in the dependencies between the sample sovereign bond yields. For example, DCC takes minimum and maximum values of −0.16 and 0.87 respectively for Germany, giving us a range greater than 1. On the other hand, DCC-MIDAS is confined to the interval (0.36, 0.76) for the same country. Table 3 presents the descriptive statistics of the DCC and the DCC-MIDAS for all sample countries. The stability of the latter is observed easily when we compare the standard deviations. In many cases, the unconditional volatility of the DCC is around twice of the DCC-MIDAS, and in some extreme cases such as Ireland, this ratio can reach up to almost 4. The volatile movement of the short-term correlation component is also reflected in the mean correlation values. Without an exception, DCC mean stays below the DCC-MIDAS

Table 2
GARCH-MIDAS and DCC-MIDAS parameter estimates.

GARCH-MIDAS	μ	α	β	θ	ω_v	$\overline{m}$
Austria	−0.00042	0.05459	0.93997	0.25437	1.00100	0.00000
	(0.00053)	(0.00407)	(0.00425)	(0.03238)	(0.02891)	(171.44)
Belgium	−0.00104	0.09923	0.67660	0.18999	27.08200	0.02242
	(0.00061)	(0.01062)	(0.0384)	(0.00572)	(2.8765)	(0.00141)
Finland	−0.00098	0.03926	0.92611	0.19108	9.49880	0.02127
	(0.00059)	(0.00448)	(0.01276)	(0.00907)	(2.69)	(0.0025)
France	−0.00090	0.03093	0.96232	0.15435	1.06400	0.02865
	(0.00057)	(0.00286)	(0.00377)	(0.03879)	(0.33794)	(0.00781)
Germany	−0.00089	0.02760	0.96889	0.00080	1.00100	0.04180
	(0.00056)	(0.00246)	(0.00296)	(12.652)	(3125.9)	(0.00976)
Greece	−0.00109	0.30082	0.68167	0.50988	27.27800	0.06422
	(0.00085)	(0.00639)	(0.00743)	(0.04422)	(1.4753)	(0.00737)
Italy	−0.00080	0.09311	0.83452	0.20769	13.72400	0.02215
	(0.00069)	(0.00616)	(0.01403)	(0.00609)	(1.7153)	(0.00257)
Ireland	0.00100	0.05000	0.90000	0.10000	5.00000	0.01000
	(0.00037)	(0.00097)	(0.00265)	(0.00167)	(0.39328)	(0.0003)
Netherlands	−0.00103	0.04033	0.84779	0.20352	22.58900	0.01632
	(0.00057)	(0.00825)	(0.04685)	(0.00612)	(4.2865)	(0.00192)
Portugal	−0.00112	0.12967	0.78231	0.22783	16.69100	0.02022
	(0.00073)	(0.00825)	(0.01213)	(0.00388)	(1.4614)	(0.00236)
Spain	−0.00105	0.09353	0.83146	0.20322	12.69700	0.02248
	(0.00064)	(0.00732)	(0.01522)	(0.0066)	(1.8036)	(0.00237)
Benchmark	−0.00120	0.15900	0.72046	0.24749	24.39200	0.00756
	(0.00049)	(0.00789)	(0.01945)	(0.0034)	(2.3384)	(0.00251)

DCC-MIDAS	a	b	ω_c
Parameter values	0.01519	0.97979	1.54720
	(0.00018)	(0.00026)	(0.02881)

Notes: The top panel reports the estimates of the GARCH-MIDAS coefficients for the sovereign bonds. The bottom panel reports the estimates of the DCC-MIDAS parameters. Standard error of the coefficient estimates are given in the parenthesis. The number of MIDAS lags is 20 for the GARCH process and 120 for the DCC process.

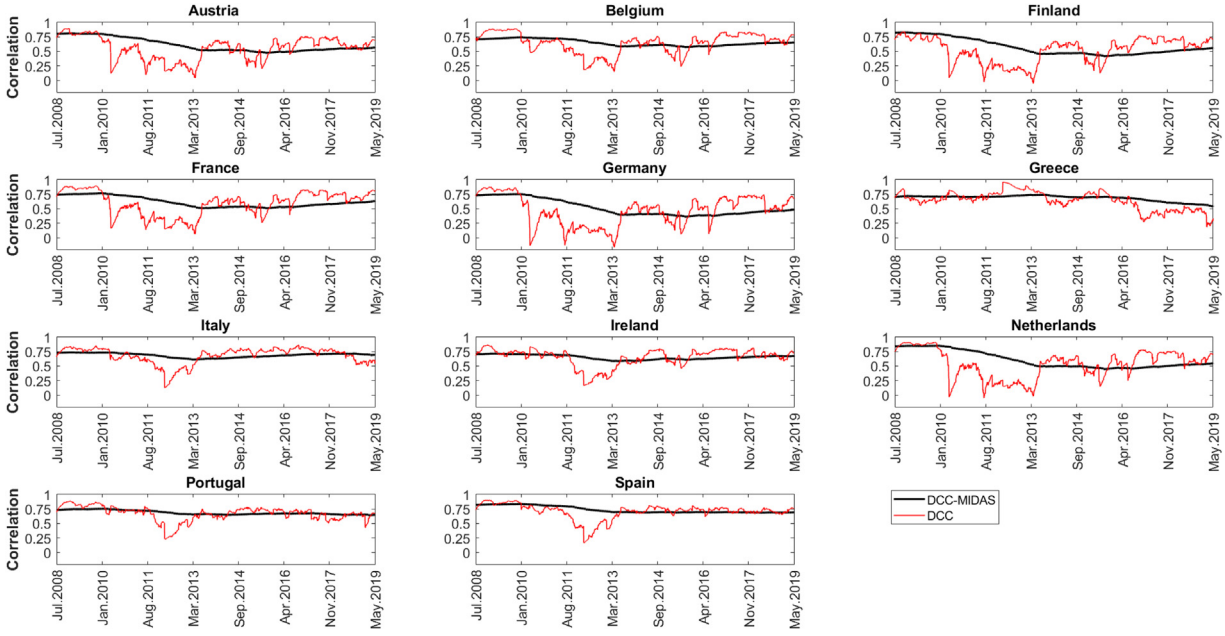

Fig. 3. Long-run vs short-run dynamic correlations. Note: The figure shows the dynamic correlations between individual sovereign bond yields and the aggregate EMU sovereign bond market yield.

mean, indicating of a potential underestimation of the contemporaneous relationship between the sample sovereign bond markets. Furthermore, according to the ADF test results applied to the DCC, there is no trend in short-term correlations for any of the countries, whereas the same test reveals the existence of a negative significant trend in 7 countries. To the extent that in this paper, our focus is the impact of regulatory changes on the structural interdependencies (not the momentarily effects), it is clear that DCC-MIDAS is the right tool for us to consider from now on.

For each country, Fig. 4 displays the long-run dynamic correlations between individual sovereign bond yields and the aggregate sovereign bond market yield. The shaded areas refer to the calendar months of the regulatory changes. This figure suggests that there might be a significant relation between the regulatory actions and

Table 3
Summary statistics and results of unit root tests for long-run (DCC-MIDAS) and short-run (DCC) correlations.

		Austria	Belgium	Finland	France	Germany	Greece	Italy	Ireland	Neth.	Portugal	Spain
Mean	DCC-MIDAS	0.6092	0.6497	0.5770	0.6130	0.5163	0.6834	0.6870	0.6529	0.6049	0.6860	0.7356
	DCC	0.5504	0.6392	0.5189	0.5910	0.4657	0.6438	0.6812	0.65079	0.5334	0.6686	0.7040
Max	DCC-MIDAS	0.8099	0.7416	0.8262	0.7652	0.7519	0.7379	0.7353	0.71563	0.8504	0.7523	0.8347
	DCC	0.8940	0.8903	0.8407	0.8977	0.8744	0.9585	0.8594	0.86351	0.9098	0.8870	0.9047
Min	DCC-MIDAS	0.4738	0.5726	0.4193	0.5096	0.3626	0.5379	0.6146	0.58660	0.4499	0.6427	0.6841
	DCC	0.0444	0.1522	−0.0498	0.0631	−0.1622	0.1851	0.1268	0.16640	−0.0524	0.2290	0.1674
Std. Dev.	DCC-MIDAS	0.1157	0.0552	0.1377	0.0885	0.1373	0.0494	0.0367	0.03957	0.1462	0.0363	0.0584
	DCC	0.1986	0.1754	0.2151	0.2091	0.2534	0.1543	0.1403	0.14950	0.2403	0.1249	0.1333
Kurtosis	DCC-MIDAS	1.8077	1.5565	1.9011	1.7593	1.7981	3.5112	1.9023	1.71638	1.7735	1.811	1.6801
	DCC	2.2968	2.8694	2.2100	2.2570	2.1657	2.8780	5.3385	4.31826	2.2322	4.8323	6.4371
Skewness	DCC-MIDAS	0.6661	0.3680	0.6852	0.5469	0.6698	−1.3404	−0.4542	−0.0098	0.6805	0.6690	0.7098
	DCC	−0.4605	−0.7767	−0.6628	−0.5686	−0.3246	−0.4877	−1.5320	−1.3623	−0.3954	−1.1331	−1.6825
Jarque–Bera	DCC-MIDAS	379.0	311.3	365.9	324.4	384.1	883.3	240.8	195.4	398.1	379.7	445.6
	DCC	159.2	288.2	282.4	218.8	132.5	114.6	1761.9	1086.4	144.1	1007.2	2743.8
ADF	DCC-MIDAS	−4.5***	−1.3	−4.6***	−2.2	−3.8***	−3.7***	−1.2	−0.8	−4.8***	−2.7*	−4.2***
	DCC	−0.8	−0.4	−0.7	−0.5	−0.9	−0.9	−0.6	−0.4	−0.8	−0.5	−0.3

Notes: Asymptotic critical values for the ADF test are −3.43, −2.86 and −2.57 for 1%, 5% and 10% significance levels respectively.

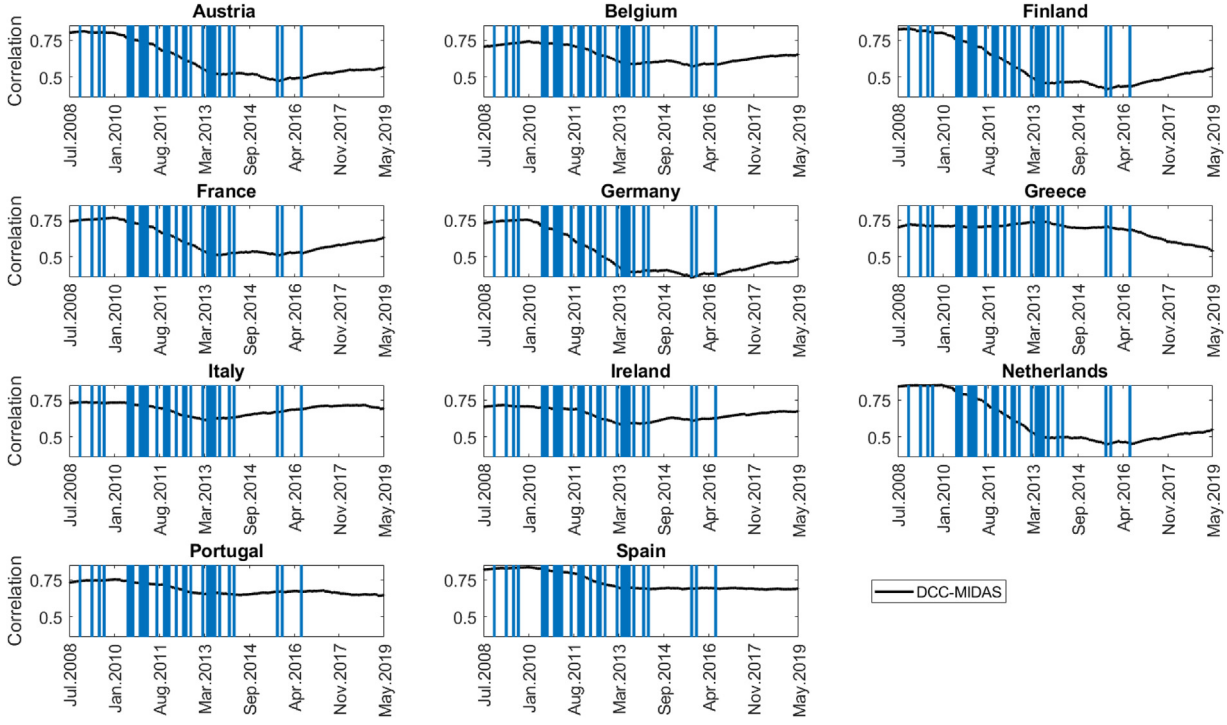

Fig. 4. Long-run dynamic correlations with applied regulatory changes. Note: The dynamic correlations above are between individual sovereign bond yields and the aggregate EMU sovereign bond market yield. The shaded areas denote the months of the regulatory changes.

the long-run dependencies. To officially test this, we start with the following simple model:

$$\bar{\rho}_t = c_0 + c_1 D_t^{1m} + \epsilon_t \tag{11}$$

In Eq. (11), $\bar{\rho}_t$ is the DCC-MIDAS and the D_t^{1m} is a dummy variable that takes one in the calendar month that the regulatory action is taken, and otherwise zero. We call this type 1 model and it basically shows us whether there is a significant relationship between the regulatory actions and the long-run correlations among bond yields within the month of actions. Table 4 displays the estimation results. All countries except Ireland generate significant results. We further check whether this significant impact is transitory or not, so we estimate the same model type but change the dummy variable D_t^{1m} to D_t^{2m} where the new dummy variable takes one in not only the calendar month of the regulatory action but also in the following calendar month. Table 4 shows that all dummy variables are significant, with however the opposite sign compared to the estimation results when we use D_t^{1m}. This presents an interesting case and might be an indicator of the investors' overreaction to the regulatory changes within a short time frame.

One might argue that the significant impact of the regulatory changes might arise due to the trend in the long-run correlations. Indeed, it might actually be the case since some of the long-run correlations have been found to be non-stationary as displayed in Table 3. To control for the trend effect, we estimate the model in the following equation:

$$\bar{\rho}_t = c_0 + c_1 D_t^{1m} + c_2 t^{1m} + \epsilon_t \tag{12}$$

We call the model in Eq. (12) type 2 and it basically shows us whether there is a significant relationship between the regulatory actions and the long-run correlations among bond yields within the month of actions when we control for the trend in the correlations. According to Table 4, trend term coefficients are found to

Table 4
Impact of regulatory changes in the long-run dynamic correlations.

Country	Model	D_t^{1m}	D_t^{2m}	$t^{1m} \times 10^4$	$t^{2m} \times 10^4$
Austria	1	0.045***	−0.089***	–	–
	2	−0.025***	0.017***	−1.229***	−1.205***
Belgium	1	0.019***	−0.037***	–	–
	2	−0.010***	0.006**	−0.500***	−0.490***
Finland	1	0.045***	−0.103***	–	–
	2	−0.036***	0.018***	−1.405***	−1.367***
France	1	0.020***	−0.054***	–	–
	2	−0.026***	0.015***	−0.806***	−0.779***
Germany	1	0.049***	−0.105***	–	–
	2	−0.032***	0.017***	−1.417***	−1.383***
Greece	1	0.040***	−0.049***	–	–
	2	0.014***	−0.008***	−0.444***	−0.458***
Italy	1	−0.014***	0.010***	–	–
	2	−0.020***	0.019***	−0.113***	−0.099***
Ireland	1	−0.002	−0.011***	–	–
	2	−0.017***	0.009***	−0.248***	−0.231***
Netherlands	1	0.061***	−0.119***	–	–
	2	−0.030***	0.016***	−1.567***	−1.536***
Portugal	1	0.015***	−0.026***	–	–
	2	−0.007***	0.008***	−0.385***	−0.381***
Spain	1	0.028***	−0.049***	–	–
	2	−0.009***	0.007***	−0.642***	−0.634***

Notes: In this table, Model 1 and Model 2 represent the regressions without and with the trend variable, respectively. D_t^{1m} refers to the coefficient of the dummy variable that takes the value one in the calendar month that the regulatory action is taken, and otherwise zero. Similarly, D_t^{2m} refers to the coefficient of the dummy variable that takes the value one in the calendar month that the regulatory action is taken and also the following calendar month, otherwise zero. t^{1m} (t^{2m}) refers to the trend coefficient when we estimate the Model 2.

Table 5
This table shows the dates of the long-run correlation shifts for each sovereign bond detected by Lavielle's penalized contrasts methodology with allowance for different number of maximum break points.

Austria	Belgium	Finland	France	Germany	Greece	Italy	Ireland	Netherlands	Portugal	Spain
(a) Panel A: Maximum number of allowed break points is three										
08/06/2010	14/02/2012	15/02/2011	05/07/2011	05/07/2011	06/05/2014	22/11/2011	13/03/2012	28/09/2010	23/11/2010	28/09/2010
30/08/2011	18/12/2012	25/09/2012	25/09/2012	20/11/2012	13/12/2016	17/11/2015	15/11/2016	20/12/2011	10/04/2012	20/12/2011
20/11/2012	25/07/2017	17/10/2017	02/05/2017	17/10/2017	17/10/2017			18/12/2012	14/11/2017	25/09/2012
(b) Panel B: Maximum number of allowed break points is six										
08/06/2010	30/08/2011	08/06/2010	03/08/2010	08/06/2010	05/06/2012	31/08/2010	11/05/2010	03/08/2010	28/09/2010	31/08/2010
05/07/2011	08/05/2012	05/07/2011	05/07/2011	15/02/2011	11/03/2014	22/11/2011	20/12/2011	02/08/2011	20/12/2011	05/07/2011
08/05/2012	15/01/2013	08/05/2012	10/04/2012	30/08/2011	31/05/2016	08/05/2012	03/07/2012	08/05/2012	10/04/2012	20/12/2011
15/01/2013	05/05/2015	12/02/2013	18/12/2012	05/06/2012	07/02/2017	29/07/2014	29/07/2014	15/01/2013	28/08/2012	10/04/2012
10/02/2015	13/12/2016	19/09/2017	10/01/2017	12/02/2013	17/10/2017	17/11/2015	07/02/2017	10/02/2015	30/06/2015	28/08/2012
10/01/2017	12/12/2017		06/03/2018	17/10/2017	16/10/2018	18/10/2016		19/09/2017	14/11/2017	12/02/2013
(c) Panel C: Maximum number of allowed break points is nine										
08/06/2010	17/02/2009	08/06/2010	08/06/2010	08/06/2010	05/06/2012	03/08/2010	13/04/2010	08/06/2010	28/10/2008	28/10/2008
21/12/2010	05/07/2011	15/02/2011	15/02/2011	15/02/2011	22/10/2013	07/06/2011	27/09/2011	18/01/2011	31/08/2010	03/08/2010
02/08/2011	20/12/2011	02/08/2011	02/08/2011	02/08/2011	08/04/2014	20/12/2011	17/01/2012	02/08/2011	12/04/2011	15/02/2011
10/04/2012	08/05/2012	13/03/2012	14/02/2012	14/02/2012	12/01/2016	10/04/2012	05/06/2012	14/02/2012	20/12/2011	30/08/2011
20/11/2012	15/01/2013	25/09/2012	03/07/2012	03/07/2012	20/09/2016	25/09/2012	18/12/2012	31/07/2012	10/04/2012	20/12/2011
09/04/2013	05/05/2015	12/02/2013	15/01/2013	12/02/2013	07/02/2017	06/05/2014	01/07/2014	12/02/2013	28/08/2012	10/04/2012
10/02/2015	13/12/2016	10/03/2015	15/11/2016	10/03/2015	19/09/2017	18/11/2014	23/08/2016	10/02/2015	30/06/2015	28/08/2012
18/10/2016	12/12/2017	13/12/2016	22/08/2017	13/12/2016	01/05/2018	15/12/2015	07/03/2017	07/02/2017	14/11/2017	12/02/2013
17/10/2017		06/02/2018	29/05/2018	12/12/2017	05/02/2019	18/10/2016	06/02/2018	06/02/2018		14/11/2017

Note: This table demonstrates the shift dates in long-run correlations when we allow for maximum number of breaks equal to 3, 6 and 9. In the analysis, we cover all possible break structures when maximum number of breaks runs through 2 to 10.

be significantly negative, yet the dummy coefficients are also still significant.

As in the previous case, we try to see if the significant impact is transitory or not, therefore replace the D_t^{1m} with D_t^{2m} in the type 2 model. Accordingly, the new dummy coefficients preserve their significance as displayed in Table 4 and the interesting case of switching signs is still there. All in all, our analysis shows that regulatory changes have significant and negative impact on the long-run relationship of sovereign bond yields of the sample countries and this significance is robust with respect to the trend in the correlations. Hence, the more the regulations the EU attempts to put in place over the long run, the lower the convergence process.

4.3. Detecting structural shifts in the long-run correlations

We now run a robustness check of the results in the previous section by detecting the structural shifts in the long-run correlations and investigating whether these shifts are associated with the regulatory changes the European Union has undertaken over our study period. To do so, we apply the state of the art penalized contrasts methodology by Lavielle (2005) to the correlation series to detect the change points. The details of the methodology are provided in Appendix C. We provide the maximum potential number of change points as an input and receive the dates of changes as the output. Table 5 demonstrates the change (or break) point dates for each country's sovereign bond yield correlations when we allow

Table 6
Important events that potentially created shifts in the long-run correlations

Shift date	Event	Source
08/06/2010	Broad fears about European financial contagion and the announcement of a tax on UK banks and a deposit guarantee schemes for bank failures	https://www.ft.com/content/7e0186ac-71aa-11df-8eec-00144feabdc0 https://www.spiegel.de/international/germany/radical-cutbacks-german-government-agrees-on-historic-austerity-program-a-699229.html
05/07/2011 02/08/2011 30/08/2011	New Greek bailout tranche and a sharp escalation of the Greek crisis	https://www.telegraph.co.uk/finance/economics/8620735/The-challenges-facing-Christine-Lagarde.html
20/12/2011	Regulation shifts/announcement	https://www.telegraph.co.uk/finance/comment/damianreece/8971513/Eurozone-zombies-follow-Mario-Draghis-cheap-money.html
14/02/2012	First major broad EU credit ratings cut	https://www.forbes.com/sites/afontevecchia/2012/02/13/moodys-cuts-peripherals-scrutinizes-france-and-britains-triple-as/
10/04/2012	Cypriot financial problems escalate sharply	https://www.ft.com/content/f209b43c-8316-11e1-929f-00144feab49a
08/05/2012	European austerity measures are reported to be broadly damaging numerous European real economies	https://www.telegraph.co.uk/news/worldnews/europe/eu/9252941/Europe-austerity-crisis-Q-and-A.html
03/07/2012	Start of the Brexit process and major regulatory developments (Insurance, BRRD, PRIPS, IMD, UCITS)	https://www.news24.com/World/News/Cameron-under-pressure-over-EU-referendum-20120702 https://www.independent.co.uk/news/world/europe/what-if-britain-left-the-eu-7904469.html http://europa.eu/rapid/press-release_MEMO-12-516_en.htm?locale=en
25/09/2012	Basel III regulations and rules on high frequency trading	https://www.bis.org/publ/bcbs229.pdf
20/11/2012	New EU data protection regulation	https://www.lexology.com/library/detail.aspx?g=36c4f233-a484-41b2-9fc1-65e9db2cb0a0
18/12/2012	EU ODR regulation	http://europa.eu/rapid/press-release_MEMO-12-994_en.htm
15/01/2013	EU credit rating agencies regulation	http://europa.eu/rapid/press-release_MEMO-13-13_en.htm
10/03/2015	Beginning of EU quantitative easing	https://www.euractiv.com/section/euro-finance/news/ecb-euro-central-banks-begin-qe-stimulus-programme/
07/02/2017	EU securitization problem due to Brexit	https://www.ft.com/content/b47104c6-ea32-11e6-893c-082c54a7f539

Note: The first column represents the long-run correlation shift dates that are common for at least five sample countries. The second column provides the events that might be associated with these shifts and the sources of these events are provided in the third column.

for the number of maximum break points as 3 (Panel A), 6 (Panel B) and 9 (Panel C).

In our extended analysis, we allow for the maximum number of break points to run from 2 to 10, and then select the dates that are common for at least 5 sample countries. Table 6 provides the break dates with the potential reasons causing the shifts. It is clear that the break dates mostly fall into the years 2011 and 2012, when the European sovereign debt crisis reached its peak with various regulations being put into place to control the situation. When we take a detailed look at the potential sources, we see a variety of regulatory actions taken by the European Commission and the Basel Committee. In addition to those, major economical events such as the fear of contagion in Europe, Greek bailout programme, credit rating cuts in the EU and the quantitative easing in the eurozone stand out as potential sources. Finally, we see that political events, in particular various stages of the Brexit process, also seem to have a significant impact on shaping the long-run correlations between the core eurozone countries' sovereign bond markets.

To sum up, long-run correlations between the EMU sovereign bond markets are characterized by occasional structural shifts which mostly took place during the times of regulatory changes in order to deal with the sovereign debt crisis or important economic and political events (e.g., credit rating downgrades in Europe and the Brexit). This finding strengthens the argument that both political and economic uncertainties as well as the key regulatory actions are drivers of the long-run relationship between the sovereign bonds of major eurozone member countries.

5. Discussion and conclusion

This research identifies and examines the impact of European regulatory changes on the structural interdependencies of EMU sovereign bond markets as well as to discuss its implications for the future of regulations. To complete this task, we utilize the DCC-MIDAS methodology which allows for baseline correlation levels to vary slowly throughout the period under investigation. One of the key issues identified during the process of European integration was based on the fact that broad regulation, with particular emphasis on its uniformity, might actually be hindering broad growth of some domestic and more peripheral and locally-designed markets. Our selected countries include not only core European states such as France, Germany, Austria, Belgium and the Netherlands, but also the more problematic and peripheral states referred to as the PIIGS; i.e., Portugal, Italy, Ireland, Greece and Spain.

The empirical results obtained from using the DCC-MIDAS framework show that regulatory changes have significant impacts on the long-run relationship among sovereign bond yields of the sample countries and this significance is robust with respect to the trend in the correlations. The methodological selection is validated when documenting the differing behaviour of both the long- and short-term correlation components between individual sovereign bond yields. As to the exceptional nature of the influence of the financial crises and sovereign debt crises that affected Ireland, Greece, Spain, Portugal and Italy, we find substantial evidence of significant effects of regulatory announcements during the period analysed.

Our analysis also examines the structural shifts in the long-run correlations with respect to regulatory change announcements (both the regulatory announcements that have been both announced and fully implemented and those that are currently being implemented and have not yet reached conclusion). It was broadly assumed that market responses to regulatory change announcements would be substantial at the point that such information of large structural changes being announced. This turns out to be the case, with sharp responses in the DCC-MIDAS framework observed during key events such as the provision of financial support for Greece. The detailed analysis of the results shows that European bond markets were sharply influenced through the implementation of key regulations undertaken by the European Commission and the Basel Committee, such as BRRD, PRIPS, IMD, UCITS, Basel III, data protection regulation, EU ODR regulation, and the regulation of EU credit ratings agencies. These substantial shifts

in long-run correlations mainly occur during key periods of financial market stress in 2012 (e.g., the first phase of European sovereign credit ratings cut and the escalation of the Cypriot financial crisis) and during the decision to provide European quantitative easing. The announcement of Brexit and key dates related to its subsequent escalation also trigger shifts in correlations. Another key result is the sharp divergence in bond performance for Greek bond markets when compared to other European markets during the most severe episodes in 2011.

We contribute to the literature by showing that the regulatory changes in Europe have significant and negative impact on the long-run correlations of the sovereign bond markets of the major eurozone countries. Moreover, the more the regulations the EU attempts to put in place over the long run, the lower the convergence process. Overall, our findings suggest that, when considering to implement new regulations, the EU policymakers should carefully pay attention to the potential uniquenesses of different member countries in order to preserve financial stability and to advance the convergence to the eurozone single market. The reason is that the international regulatory principles are more likely applicable for entities or activities of international relevance. For example, the cost of complying with the EU prudential regulation, which is contained in the Capital Requirements Directive (CRD) and Capital Requirements Regulation (CRR), disproportionally differs between small-sized and large-sized firms.[6] Future research can focus on figuring out whether the regulations analysed in this study (or a specific subset of them) have a homogeneous effect on the EMU sovereign bond markets and if so, why.

Authors' contribution

Erdinc Akyildirim: conceptualization, software, formal analysis; Shaen Corbet: conceptualization, writing – review & editing, visualization; Duc Khuong Nguyen: conceptualization, methodology, supervision, writing – review & editing; Ahmet Sensoy: conceptualization, methodology, supervision, and writing-original draft.

Appendix A. Financial reforms that are put in action

Appendix A: Financial reforms implemented by the European Commission after the European financial crisis.

Date	Action name	Brief description
Jul-07	Risk-based prudential and solvency rules for insurers ('Solvency II')	The Solvency II regime introduces for the first time a harmonized, sound and robust prudential framework for insurance firms in the EU.
Nov-08	Credit Rating Agencies	Because there were weaknesses in the existing EU rules on credit ratings that have been highlighted both by the financial crisis and the euro debt crisis, structural improvements were made to regulation.
Apr-09	Hedge Funds and Private Equity ('AIFMD')	AIFMD was identified as a key part of the European Commission's drive to lay the regulatory foundations for a secure financial system that supports and stimulates the real economy.
Jul-09	Remuneration and prudential requirements for banks ('CRD III')	This proposal would require banks to hold capital for credit related losses short of an instrument's default, taking into account medium-term price movements in view of an impaired market liquidity for such instruments
Sep-09	Establishment of the European Supervisory Authorities	The ESRB will provide an early warning of system-wide risks that may be building up and, where necessary, issue recommendations for action to deal with these risks.
Jul-10	Deposit Guarantee Schemes	The Commission proposed new funding requirements for schemes will ensure that DGS will be able to fulfil their obligations towards depositors, and faster access to deposits after a bank failure will stabilize the confidence of depositors and ensure financial stability.
Aug-10	Strengthened supervision of financial conglomerates	The main objective of the revision of the Directive is to correct this unintended consequence of the current rules.
Sep-10	Derivatives ('EMIR')	EMIR provides a mechanism for recognising CCPs and trade repositories based outside of the EU. Once recognized, EU and non-EU counterparties may use a non EU-based CCP to meet their clearing obligations and a non EU-based trade repository to report their transactions to.
Sep-10	Short-selling and Credit Default Swaps	The EU adopted a regulation which increases transparency by requiring the flagging of short sales, so that regulators know which transactions are short; gives national regulators powers to temporarily restrict or ban short selling of any financial instrument; and requires central counter-parties providing clearing services to ensure that there are adequate arrangements in place for buy-in of shares as well as fines for settlement failure
Dec-10	Creation of the Single Euro Payments Area ('SEPA')	The regulation (EC) No. 924/2009 on charges for cross-border payments in euro was also adopted in the context of SEPA. It requires banks to apply the same charges for domestic and cross-border electronic payment transactions in euro.
Jan-11	New European supervisory framework for insurers ('Omnibus II')	Under the new regulation: (1) 'qualifying infrastructure investments' will form a distinct asset category and will benefit from an appropriate, lower risk calibration; and (2) investments in European Long-Term Investment Funds (ELTIFs) and equities traded on multilateral trading facilities (MTFs) will also benefit from lower capital charges
Feb-11	Interconnection of business registers	The key objectives are to: (1) Facilitate cross-border access to official business information by defining a common minimum set of up-to-date company information to be available to third parties in all EU languages; (2) Develop a framework for cross-border cooperation between business registers; and (3) Ensure that business registers provide up-to-date information on the status of their companies to the business registers of companies' foreign branches all across Europe.
Mar-11	Responsible lending (mortgage credit)	The mortgage credit directive is a step towards an EU-wide mortgage credit market with a high level of consumer protection.
Jul-11	Single Rule Book of prudential requirements, remuneration and improved transparency ('CRD IV/CRR')	The regulation establishes the prudential requirements that institutions need to respect. It sets out the rules for calculating capital requirements and reporting and general obligations for liquidity requirements
Oct-11	Enhanced framework for securities markets ('MIFID/R')	MiFID is the markets in financial instruments directive (Directive 2004/39/EC). In force from 31 January 2007 to 2 January 2018, it is a cornerstone of the EU's regulation of financial markets.

[6] See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52016SC0377R%2801%29 for details.

Oct-11	Enhanced framework to prevent market abuse ('MAD/R')	The new rules strengthened and replaced the original market abuse directive (MAD). Adopted in 2003, the MAD introduced a framework to harmonize core concepts and rules on market abuse and strengthen cooperation between regulators.
Oct-11	Simplification of accounting	As part of the Responsible Business package (see IP/11/1238), the Directive will reduce the administrative burden for small companies.
Oct-11	Enhanced transparency rules	The revised Directive will also provide for more harmonization concerning the rules of notification of major holdings in particular by requiring aggregation of holdings of financial instruments with holdings of shares for the purpose of calculation of the thresholds that trigger the notification requirement.
Nov-11	Enhanced framework for audit sector	These rules help to foster diversity in the audit markets and enhance investors' trust in the financial information of companies, which in turn improves the conditions for cross-border investment and economic growth in the EU.
Dec-11	Creation of European Venture Capital Funds	To protect investors, the EU has adopted a regulation introducing a key information document (KID), a simple document giving investors key facts in a clear and understandable manner. A KID is required for products including: (1) all types of investment funds; (2) insurance-based investments; (3) retail structured products; and (4) private pensions.
Dec-11	Creation of European Social Entrepreneurship Funds	The European social entrepreneurship funds (EuSEF) regulation covers alternative investment schemes that focus on social enterprises.
Mar-12	Central Securities Depositories	The aim of the proposal is to ensure that both CCPs and national authorities in the EU have the means to act decisively in a crisis scenario.
Jun-12	Prevention, management and resolution of bank crises ('BRRD')	The EU's bank resolution rules ensure that the banks' shareholders and creditors pay their share of the costs through a "bail-in" mechanism. If that is still not sufficient, the national resolution funds set up under the BRRD can provide the resources needed to ensure that a bank can continue operating while it is being restructured.
Jul-12	Improved investor information for complex financial products ('PRIPS')	The EU has adopted a regulation on PRIIPs, which obliges those who produce or sell investment products to provide investors with key information documents (KIDs).
Jul-12	Strengthened rules on the sale of insurance products ('IMD')	The sale of insurance products in the EU is regulated by the insurance distribution directive (IDD) adopted in 2016.
Jul-12	Safer rules for retail investment funds ('UCITS')	The amendments to the UCITS Directive (2009/65/EC) (UCITS V) focus on three areas: (1) clarification of the UCITS depositary's functions; (2) the introduction of rules on remuneration policies that must be applied to key members of the UCITS managerial staff; and (3) harmonization of the minimum administrative sanctions.
Sep-12	Single Supervisory Mechanism	The ECB and the national supervisors work closely together to check that banks comply with the EU banking rules and tackle problems early on.
Feb-13	Strengthened regime on anti-money laundering	The Commission's proposals update and improve the EU's existing 3rd AMLD and the Funds Transfers Regulation respectively with the aim of further strengthening the EU's defences against money laundering and terrorist financing.
Apr-13	Non-financial reporting for companies	This Directive amends Directive 2013/34/EU. The objective is to increase EU companies' transparency and performance on environmental and social matters and, therefore, to contribute effectively to long-term economic growth and employment.
May-13	Access to basic bank account/transparency of fees/switching of bank accounts	The directive on payment accounts gives people in the EU the right to a basic payment account regardless of a person's place of residence or financial situation. The directive also improves the transparency of bank account fees and makes it easier to switch banks.
Jun-13	Creation of European long-term investment funds	The European long-term investment funds (ELTIF) regulation covers funds that focus on investing in various types of alternative asset classes such as infrastructure, small and medium sized enterprises and real assets.
Jul-13	Single Resolution Mechanism	The mission of the SRB is: (1) ensuring the orderly resolution of failing banks with minimum impact on the real economy and the public finances of banking union countries; and (2) managing the single resolution fund.
Jul-13	Revised rules for innovative payment services	The EU adopted a new directive on payment services (PSD 2) to improve the existing rules and take new digital payment services into account.
Sep-13	Regulation of Financial Benchmarks	Under the new rules: (1) ensuring that benchmark administrators are subject to prior authorization and on-going supervision depending on the type of benchmark; (2) improving their governance and requiring greater transparency of how a benchmark is produced; and (3) ensuring the appropriate supervision of critical benchmarks.
Sep-13	Shadow banking, including Money Market Funds	One of the actions recommended by the communication was a proposal for money market funds (MMFs), which are mutual funds that invest in short-term debt such as money market instruments issued by banks, governments or corporations.
Jan-14	Shadow banking: increasing the transparency of securities financing transactions	The European Commission adopted a regulation on the transparency of securities financing transactions (SFTR). These rules add transparency, reporting and disclosure conditions for institutions engaged in SFTs, making it easier to monitor and assess the risks involved in these transactions.
Mar-14	Long-term financing of the European economy/Revised rules for occupational pension funds ('IORP')	The new rules aim to: (1) ensure that occupational pensions are sound and better protect pension scheme members and beneficiaries; (2) better inform members and beneficiaries about their entitlements; (3) remove obstacles faced by occupational pension funds operating across borders; and (4) encourage occupational pension funds to invest long-term in economic activities that enhance growth, environment and employment
Nov-15	New rules on prospectuses	The regulation aims to: (1) make it easier and cheaper for smaller companies to access capital; (2) introduce simplification and flexibility for all types of issuers; and (3) improve prospectuses for investors by introducing a retail investor-friendly summary of key information
Sep-15	New rules on securitization	The new EU rules on the identification of the STS criteria and the capital treatment of securitization exposures of banks take into account the conclusions of the EBA report.
Jul-16	Amended rules on European Venture Capital Funds	The European venture capital funds (EuVECA) regulation covers a subcategory of alternative investment schemes that focus on start-ups and early stage companies.

Note: The above data represents all proposals of financial reforms that are finalized and implemented by the European Commission. In many cases, all countries are allowed an adaptation period before full compliance. Data available at https://ec.europa.eu.

Appendix B. Financial reforms presented but not yet adopted

Appendix B: Financial reforms presented by the Euorpean Commission but not yet adopted.

Proposed	Action name	Brief description
Jan-14	Structural reform of banks	The proposal on the Securities Financing Transactions Regulation, aims to improve the transparency of the securities financing markets. The proposal was announced as part of the action plan on shadow banking in September 2013.
Nov-15	Proposal for a European deposit insurance scheme (EDIS)	The Commission's legislative proposal on 24 November 2015 introducing a bank depositors across the Banking Union. EDIS would develop over time and in three stages: first a re-insurance stage, then a co-insurance stage and, finally, a full European system of deposit guarantees, which is envisaged for 2024.
Nov-16	Proposals to amend rules on capital requirements	Tackle remaining weaknesses and implement some outstanding elements that are essential to ensure the institutions' resilience, which have only recently been finalized by global standard setters.
Nov-16	Proposals to amend rules on bank recovery and resolution (BRRD)	Proposals aim to tackle remaining weaknesses and implement some outstanding elements that are essential to ensure the institutions' resilience
Nov-16	Proposal to amend rules on the Single resolution mechanism (SRM)	Proposals aim to tackle remaining weaknesses and implement some outstanding elements that are essential to ensure the institutions' resilience
Nov-16	Recovery and resolution of central counter-parties (CCPs)	Proposals aim to tackle remaining weaknesses and implement some outstanding elements that are essential to ensure the institutions' resilience
May-17	Proposal to amend rules on derivatives (EMIR)	Proposals aim to tackle remaining weaknesses and implement some outstanding elements that are essential to ensure the institutions' resilience
Jun-17	2nd proposal to amend rules on derivatives (EMIR)	Proposal relies on input received from stakeholders from the public consultations on the operations of the European Supervisory Authorities (ESAs) and on the Capital Markets Union (CMU) Mid-Term Review.
Jun-17	Proposal on a pan-European Personal Pension Product (PEPP)	The Commission's proposal will lay down the foundations for a pan-European Personal Pension market, ensuring standardization of the core product features, such as transparency requirements, investment rules, switching and portability. It will ensure sufficient consumer protection on the essential features of the product, while at the same time being flexible enough to enable different providers to tailor products to suit their business model. This initiative is complementary to existing pension plans, whether state-based, occupational or personal pensions and it will not replace or substitute them.
Sep-17	Proposals to amend rules on financial supervision	The Commission is proposing to further strengthen and integrate EU financial market supervision. This requires a reinforced coordination role for all ESAs and new direct supervisory powers for ESMA. To make this work, the Commission is proposing to make the ESAs' governance and funding fit for their new tasks.
Dec-17	Proposals to review prudential rules for investment firms	This proposal aims to ensure that investment firms are subject to key prudential requirements and corresponding supervisory arrangements that are adapted to their risk profile and business model, without compromising financial stability.
Mar-18	Proposal on European crowdfunding service providers	The Commission's proposal introduces an optional EU regime which enables crowdfunding platforms to easily provide their services across the EU Single Market. Instead of having to comply with different regulatory regimes, platforms will have to comply with only one set of rules, both when operating in their home market and in other EU Member States. For investors the proposal will further provide legal certainty as regards the applicable investor protection rules.
Mar-18	Proposal for a EU framework on covered bonds	Proposals aim to boost the cross-border market for investment funds, promote the EU market for covered bonds as a source of long-term finance and ensure greater certainty for investors when dealing in cross-border transactions of securities and claims.
Mar-18	Proposal on facilitating cross-border distribution of investment funds	The Commission is committed to put in place all building blocks of the Capital Markets Union by mid-2019. The measures presented today, and the remaining CMU proposals that will be presented by May 2018 make it possible that legislation can be adopted before European Parliament elections in 2019.
Mar-18	Proposal on the law applicable to the third-party effects of assignments of claims	Proposals aim to boost the cross-border market for investment funds, promote the EU market for covered bonds as a source of long-term finance and ensure greater certainty for investors when dealing in cross-border transactions of securities and claims.
Mar-18	Proposals to address the risks related to NPLs	Ambitious package of measures is the Commission's response to the call by the Council for further measures to address the problem of non-performing loans in the EU as set out in its Action Plan of July 2017.
Mar-18	Proposal on cheaper cross-border payments in euro and fairer currency conversions across the entire EU	The two amendments proposed to Regulation 924/2009 on cross-border payments aim to reduce the cost of all intra-EU payments in euro and unify the single payment market for consumers and businesses. Today, cross-border payments in euro from non-euro area Member States can be as high as EUR 20 in some countries while equivalent cross-border payments from euro area Member States are very cheap or even free.
May-18	Proposal to amend the motor insurance directive	An obligation on motor vehicles to have a motor third party liability insurance policy, valid for all parts of the EU on the basis of a single premium. Obligatory minimum amounts of cover provided by insurance policies (Member States may require higher cover at national level). A prohibition on Member States from carrying out systematic border checks of insurance of vehicles.
May-18	Proposal on sovereign bond-backed securities	According to the criteria outlined in the Commission proposal, sovereign bond-backed securities (SBBS) would take the form of low-risk liquid assets backed by a pre-defined pool of euro-area central government bonds.
May-18	Legislative package on sustainable finance	Fostering more sustainable private investments was a key priority of the Capital Markets Union's (CMU) mid-term review. The Action Plan on Financing Sustainable Growthlaunched by the Commission on 8 March 2018 laid out a roadmap to deliver on this commitment.
May-18	Proposal on SME Growth Markets	This proposal targets amendments to EU rules for companies listed on SME Growth Markets, a recently-created category of trading venues. This is one of the numerous measures presented by the Commission since the launch of the CMU in 2015 to improve SMEs' access to market-based finance.

Note: The above data represents all proposals of financial reforms that are currently being considered by the European Commission. Data available at https://ec.europa.eu.

Appendix C. Detection of mean shifts in the long-run correlation components

We use the change point detection method of Lavielle (2005) to formally see if there is any structural change in the long-run correlations. Mathematical notations in this part are independent from the other parts of this manuscript.

We consider a sequence of random variables $Y_1, \ldots, Y_n$ that take values in $\mathbb{R}^p$. Assume that $\theta \in \Theta$ is a parameter denoting the characteristics of the Y_is that changes abruptly and remains constant between two changes. The change occur at some instants $\tau\star_1 < \tau\star_2 < \cdots < \tau^\star_{K\star-1}$. Here $K\star-1$ is the number of change points hence we have $K\star$ number of segments.[7]

Now, let K be some integer and let $\boldsymbol{\tau} = (\tau_1, \tau_2, \ldots, \tau_{K-1})$ be a sequence of integers satisfying $0 < \tau_1 < \tau_2 < \cdots < \tau_{K-1} < n$. For any $1 \le k \le K$, let $U(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k}; \theta)$ be a contrast function useful for estimating the unknown true value of the parameter in the segment k; i.e., the minimum contrast estimate $\hat{\theta}(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k})$, computed on segment k of $\boldsymbol{\tau}$, is defined as a solution of the following minimization problem:

$$U(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k}; \hat{\theta}(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k})) \le U(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k}; \theta), \quad \forall \theta \in \Theta, \tag{C.1}$$

For any $1 \le k \le K$, let G be

$$G(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k}) = U(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k}; \hat{\theta}(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k})) \tag{C.2}$$

Then define the contrast function $J(\boldsymbol{\tau}, \boldsymbol{y})$ as

$$J(\boldsymbol{\tau}, \boldsymbol{y}) = \frac{1}{n}\sum_{k=1}^{K} G(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k}) \tag{C.3}$$

where $\tau_0 = 0$ and $\tau_k = n$. When true number $K\star$ segments is known, for any $1 \le k \le K\star$, the sequence $\hat{\boldsymbol{\tau}}_n$ of change point instants that minimizes this kind of contrast has the property that

$$\boldsymbol{Pr}(|\hat{\tau}_{n,k} - \tau\star_k| > \delta) \to 0, \quad \text{when} \quad \delta \to \infty \quad \text{and} \quad n \to \infty \tag{C.4}$$

In particular, this result holds for weak or strong dependent processes.

We consider the following model

$$Y_i = \mu_i + \sigma_i \varepsilon_i, \quad 1 \le i \le n \tag{C.5}$$

where (ε_i) is a sequence zero-mean random variables with unit variance.

In the case of detecting changes in the mean, we assume that (μ_i) is a piecewise constant sequence and (σ_i) is a constant sequence. Now, even if (ε_i) is not normally distributed, a Gaussian log-likelihood can be used to define the contrast function. Let

$$U(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k}; \mu) = \sum_{i=\tau_{k-1}+1}^{\tau_k} (Y_i - \mu)^2 \tag{C.6}$$

then

$$G(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k}) = \sum_{i=\tau_{k-1}+1}^{\tau_k} (Y_i - \overline{Y}_{\tau_{k-1}+1:\tau_k})^2 \tag{C.7}$$

where $\overline{Y}_{\tau_{k-1}+1:\tau_k}$ is the empirical mean of $(Y_{\tau_{k-1}+1}, \ldots, Y_{\tau_k})$.

When the number of shift points is unknown, it is estimated by minimizing a penalized version of $J(\boldsymbol{\tau}, \boldsymbol{y})$. For any sequence of change point instants $\boldsymbol{\tau}$, let $pen(\boldsymbol{\tau})$ be a function of $\boldsymbol{\tau}$ that increases with the number $K(\boldsymbol{\tau})$ of segments of $\boldsymbol{\tau}$. Then, let $\hat{\boldsymbol{\tau}}_n$ be the sequence of change point instants that minimizes

$$F(\boldsymbol{\tau}) = J(\boldsymbol{\tau}, \boldsymbol{y}) + \varphi pen(\boldsymbol{\tau}) \tag{C.8}$$

where φ is a function of n that goes to zero at an appropriate rate as n goes to infinity. The estimated number of segments $K(\hat{\boldsymbol{\tau}}_n)$ converges in probability to $K\star$. The proper $pen(\boldsymbol{\tau})$ and the penalization parameter φ are chosen according to Lavielle (2005).

[7] $\star$ is used to denote the true value.

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