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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Identifying financial fragmentation:

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Abstract

We present a metric for financial fragmentation in the Economic and Monetary Union (EMU), based on the higher moments of the distribution of sovereign spreads relative to macro-financial fundamentals. We apply fixed parameter and rolling regressions to allow for time variation in this relationship, while controlling for market sentiment. The metric shows that the observed moments of the spread distribution occasionally overshot the fundamentals-based benchmark until 2018. Since then, the moments of observed spreads have generally not exceeded the fundamentals-based moments, also not in the most recent period, despite the increase in interest rates. The latter may be attributed to backstop facilities of the European Central Bank (ECB), such as the Transmission Protection Instrument (TPI).

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1. Motivation

The ECB's role to address financial fragmentation has gained new impetus with the introduction of its TPI backstop tool in July 2022. This instrument has been designed to counteract a deterioration in financing conditions that is not warranted by country-specific fundamentals, to safeguard the transmission mechanism. Activation of TPI will be based on a range of market and transmission indicators, of which sovereign spreads are a key element. The importance of these spreads extends beyond sovereign debt markets, as they also affect financing conditions of firms and households seeking funding in financial markets or via bank loans.

Unwarranted spread widening may be driven by non-fundamental factors like investors' risk aversion and market sentiment. This should be distinguished from justified or fair spread widening, which can be defined as market pricing that reflects underlying risk differences across countries based on macro-economic fundamentals. Such fair market pricing is more likely in orderly market conditions, while unwarranted spread widening is often associated with market dysfunction or excessive speculation. Conceptually, fragmentation is similar to (the absence of) financial integration or the law of one price. Fragmentation may also be reflected by non-price conditions, such as restricted access to financial products. We focus on fragmentation as reflected in price differentials, more in particular on differences in sovereign spreads.

In practice, it is hard to distinguish unwarranted from fair movements in spreads. It may be even more challenging to assess whether the distribution of country-specific spreads are in line with fundamentals. Controlling for fundamentals is critical, however, to assess whether central bank interventions are justified to address disorderly market conditions that could impair monetary transmission. Our study provides a metric to assess whether the higher moments of the distribution of sovereign spreads in the euro area significantly deviate from the moments of macro-financial fundamentals, which would signal fragmentation and a reason for the ECB to intervene. It exploits both the cross-country and cross-time information in the distribution of sovereign spreads.

The rest of the paper is structured as follows. In the next section, we discuss some of the main findings in related studies. Section 3 describes the data and the observed moments of the distribution of sovereign spreads. Section 4 explains the model that we use to predict the higher moments of sovereign spreads. Section 5 describes the model results. In Section 6 we investigate the role of monetary policy with regard to financial fragmentation. Section 7 provides robustness tests and the last section concludes.

2. Findings in the literature

In the empirical literature, fragmentation is typically measured by interest rate or credit spread differentials which cannot be explained by fundamentals. To control for these fundamentals, some studies compare countries with the same credit rating or, alternatively, explain interest rate spreads by macro-financial variables such as GDP growth and debt ratios.[1] Any remaining spread difference would then be attributed to non-fundamental fragmentation.

In addition, recent studies show that the explanatory power of macro-economic variables for sovereign spreads is time-varying and differs across regimes. Eijffinger and Pieterse-Bloem (2022) apply a multidimensional factor model to regress sovereign spreads of EMU countries on macro-economic, market risk and EMU-specific factors. They find that the model is not statistically stable and robust when only macro-economic fundamentals are included, while financial market variables and central bank asset purchases are significant explanators for sovereign spreads after 2012. They attribute the failure to identify one general robust model to the presence of different regimes in the distribution of EMU sovereign bond spreads. While Eijffinger and Pieterse-Bloem exploit the time dimension of sovereign spreads, De Grauwe and Ji (2021) exploit the cross-country dimension. Based on a finite mixture model they find that in weaker EMU countries the macro-economic variables have a higher loading on sovereign spreads than in stronger countries, indicating that there is an amplification effect in weaker countries. They conclude that the willingness of the ECB to act as lender of last resort in sovereign bond markets reduced the fragility of EMU countries. Delatte et al. (2017) conclude that banking sector risks matter for sovereign spreads. Based on a panel smooth threshold regression model, they find that investors penalized a deterioration of macro-

[1] See e.g. Baele et al. (2004), De Santis (2018), Eisenschmidt et al., (2018), Garcia-de-Andoain at al. (2014), Horny et al. (2016), Mayordomo et al. (2015), Zaghini (2016), Ceci and Pericoli (2022).

economic fundamentals more strongly between 2010 and 2012, with an extra premium related to bank credit risk.

High-frequency measures are an alternative approach to assess fragmentation. An example is the ECB's price-based financial integration index (ECB, 2022), which includes a cross-country standard deviation of sovereign bond yields. This approach does not incorporate macro-fundamentals, implicitly assuming that these are moving much more slowly than the high-frequency indicator.[2]

We add to the literature by modelling the *distribution* of EMU jurisdictions' sovereign spreads across time as a function of the distribution of macro-economic variables. This results in an area-wide assessment of fragmentation, which supplements country-by-country spread deviations. The distribution of sovereign spreads reflects differences of sovereign credit risk. So we define financial fragmentation in terms of sovereign credit risk, or default risk, of EMU countries. This differs from studies that take bond yields instead of spreads as a dependent variable (e.g. Hondroyiannis and Papaoikonomou, 2022). Bond yields also capture other risk components, in particular duration risk as reflected in the tern premium, which could be driven by other factors than country-specific fundamentals such as expectations about monetary policy.

We characterize the distribution of sovereign spreads by its higher-order moments: standard deviation (*stdev*), skewness (*skew*) and kurtosis (*kurt*, reflecting the tailedness). The higher moments of the spread distribution are explained by similar moments of variables that reflect countries' macro-economic and financial fundamentals; the unexplained part is interpreted as (unwarranted) fragmentation. Our specifications allow for time variation in this relationship, while controlling for market sentiment. This is conducted by a novel application of fixed and time-varying parameter regressions. We assess to what extent the deviations of the spread distribution relative to that of macro fundamentals are excessive. Drivers of such unwarranted fragmentation – speculation, or market dysfunction – are likely to affect several countries simultaneously due to common characteristics or spillovers.

[2] As this ECB indicator is available at a daily frequency, incorporating fundamentals is difficult – as these are typically monthly or quarterly data – and may not even be needed in a high frequency indicator, as fundamentals are unlikely to change so fast.

3. Higher moments of fragmentation

3.1 Distribution moments

For the distribution of sovereign spreads we use the standard sample moments.[3] Sample moments correct for the bias or deviation between the average empirical value and the theoretical value of standard deviation, skewness or kurtosis. Their dependence on the mean of the distribution ($\bar{X}$) and terms raised up to the third (skewness) and fourth (kurtosis) power make the standard moments sensitive to outliers and observations in the far tails of the distribution. For that reason, some studies use alternative measures of distribution moments, so-called robust moments. Such moments are based on the median instead of the mean value, like the median absolute deviation (MAD) as a measure of dispersion. Other robust measures are based on quantiles instead of the mean value, such as a quantiles-based skewness and kurtosis measures (as defined by Hinkley (1975) and Moors (1988)). While these measures are more robust to outliers than the standard moments, they are also criticized for being insensitive to the distribution of X any further into the tails than the quartiles (Eberl and Klar, 2022). Furthermore, like other distribution measures, they require an evaluation of the density of the underlying distribution, based on bandwidth selection and so leads to a certain arbitrariness. Rather large sample sizes are desirable to reliably represent the population being sampled.

For the purpose of our paper, we therefore stick to the standard moments. Their sensitivity to the tails of the distribution is actually a desirable feature as it may reflect unwarranted widening of spreads driven by non-fundamental factors, like market dysfunction and investor sentiment. Such factors may lead to excessive spread levels, which are informative for the central bank to assess financial fragmentation. This information would not, or to a lesser extent, show up in the robust moments. Moreover, the small sample of countries makes it less appropriate to use moments based on quantiles. To check for the difference between the model estimations based on the mean and the median of the response variable (i.c. the moments of sovereign spreads), in Section 7 we estimate the model based on quantile regressions as a

[3] Standard formulas of the higher sample moments are as follows:

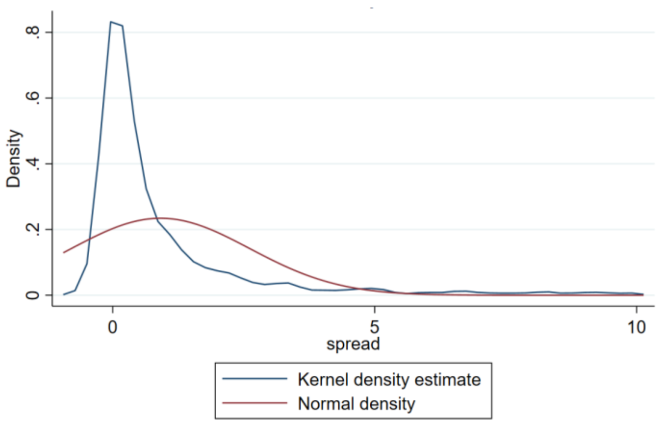
$$stdev = \sqrt{\frac{\Sigma(X-\bar{X})^2}{n-1}}, \quad skew = \frac{n\sqrt{n-1}}{(n-2)} \frac{\frac{1}{n}\Sigma(X-\bar{X})^3}{[\frac{1}{n}\Sigma(X-\bar{X})^2]^{3/2}}, \quad kurt = \frac{n(n+1)(n-1)\Sigma(X-\bar{X})^4}{(n-2)(n-3)(\Sigma(X-\bar{X})^2)^2}$$

robustness test. This approach estimates the conditional median of response instead of the mean response, which makes quantile regression estimates more robust against outliers in the response variable (i.c. the sample moment, which itself is determined by the mean of the distribution ($\bar{X}$) in the formulas of the standard sample moments).

3.2 Descriptive statistics

Our dataset of sovereign spreads and macro-economic variables covers 11 EMU countries over the 2005m9-2023m2 sample period. The sovereign spread is computed as the 10 years sovereign bond yield for each country minus the 10 years Overnight Index swap rate (OIS). The OIS rate is a proxy for the euro area risk free yield. The data reveal that the sovereign spreads are not normally distributed. The distribution of spreads across time and countries is more skewed and fat-tailed than the standard normal distribution (Fig. 1).[4]

Figure 1, Observed vs standard normal distribution of sovereign spreads across time and countries



Another insight from our dataset is that the moments of the spread distribution are time varying (Fig. 2). Spread dispersion (*stdev*) peaked in the 2012 sovereign debt crisis, indicating a high deviation of spreads from their mean value. *Skew* showed an upward trend until 2015, after which it declined. Most of the time *skew* was larger than 0.5, indicating a greater risk of extreme high spreads than low spreads. *Kurt*

[4] This is indicated by *skew* exceeding the normal distribution range of -0.5 - +0.5 and *kurt* exceeding the normal value 3. We include 11 EMU countries in our analysis (AT, BE, DE, FI, GR, IT, IR, NL, PT, ES, FR).

peaked in 2010, 2012 and 2015 and nearly always displayed excess kurtosis compared to the kurtosis of a normal distribution (i.e. a level of 3). At these points in time the ECB announced or activated asset purchase programmes, such as the Securities Markets Programme (SMP), Outright Monetary Transactions (OMT) and Public Sector Purchase Programme (PSPP). This suggests a relationship between asset purchases and the spread distribution. Figure 2 shows that the peaks of the three moments of the sovereign spread distribution occasionally coincide, but also differ across time. This means that *stdev*, *skew* and *kurt* contain their own, specific information about sovereign credit risk, particularly until 2015. Since then, the three moments share a common downward trend.

Figure 2, Moments of sovereign spread distribution over time

Note: the vertical lines show the announcement dates of the ECB's asset purchase programmes: Securities Markets Programme (SMP), Outright Monetary Transactions (OMT), Public Sector Purchase Programme (PSPP), Pandemic Emergency Purchase Programme (PEPP) and Transmission Protection Instrument (T PI).

The higher moments of the sovereign spread distribution likely reflect uneven monetary transmission across the euro area. A higher standard deviation means that financial conditions are more dispersed across EMU member states. A right-skewed distribution implies that a cluster of countries is faced with higher spreads than other countries, so monetary policy may have asymmetric effects. A high kurtosis implies that sovereign spreads occasionally are at extreme (low or high) levels, displaying fat-tailedness which can be associated with stressed market conditions and elevated risk aversion. The moments of the spread distribution can thus indicate financial fragmentation and risks to monetary transmission. Higher moments of distributions are also used in other disciplines to detect critical changes. In the literature on complex systems, for instance, the variance and skewness of a state variable is used as a signal to detect whether an environmental system is close to a critical transition (see Scheffer et al. 2009 for an overview).

3.3 Small sample concerns

A limitation of our dataset is the small population. There are only 12 countries that have been EMU member states since 2005, when our sample period starts. In fact, as we exclude Luxembourg, for which there is a lack of data to compute our metric, we only include data from 11 countries. Statistical measures derived from smaller populations usually exhibit more variability compared to measures based on larger populations (Chen et al., 2017). Hence, the small population makes the computed moments sensitive to changes in spreads of individual countries. The implicit assumption of our approach is that the observations are realizations of random variables from an underlying distribution of sovereign spreads and macro-economic variables. The limitation to operationalize this assumption (as for instance conducted by Jarner and Kryger, 2011) is that there is no larger reference population of countries available that shares the same features as our population of interest.

To further investigate the possible impact of the small sample size on our results, we construct a reference population for spreads. More specifically, we generate artificial samples by bootstrapping the sovereign spreads. For each time period in the sample we randomly draw, with replacement, 11 spread values. We compute the *stdev*, *skew* and *kurt* of these bootstrapped series. We iterate this procedure 1,000 times, which provides 1,000 values of the spread moments for each time period in the sample, i.e. for each month between 2005m9 and 2023m2. This enables us to compare the observed moments with the median and interquartile of the bootstrapped spread moments (see Annex 1). The median of the artificial *stdev* is similar to the observed *stdev*; statistical tests suggests that we cannot reject the hypothesis that both have equal mean and equal variance. The bootstrapped series for *skew* and *kurt* deviate more significantly from the observed moments and are often outside the interquartile range of the surrogate spread distributions. Overall, the first moment (*stdev*) of sovereign spreads seems robust, while the third and fourth moments (*skew* and *kurt*) are more likely suffer from small sample issues.

4. Model

To make a model-based assessment of spread moments that can be attributed to macro-fundamentals, we follow a two-stage procedure. In the first stage, we regress higher moments of the spread distribution (denoted MS_t) on similar moments of macro-economic variables (MF_t) and on market sentiment (S_t):

The time-varying model is specified as follows:

$$MS_t = \alpha_t + \beta_t' \, MF_t + \gamma_t \, S_t + \lambda_t' \, (MF_t - \overline{MF}) \, (S_t - \bar{S}) + \varepsilon_t \qquad (1)$$

We estimate three variants of the model, with MS_t and MF_t being either *stdev*, *skew* or *kurt*. MF_t is a vector of macro-economic variables *1...j*. We include GDP growth, headline inflation, the public debt-to-GDP ratio and current account balance, following De Grauwe and Ji (2021). We also add variables that capture the sovereign bank nexus and economic policy uncertainty.[5] The response of the spread moments to moments in the explanatory macro-economic variables is assumed to be fair as they represent countries' fundamentals.

Our market sentiment variable S_t and the interaction term are included as controls. As a result, vector β' measures the effect of fundamentals on spreads without being confounded by market sentiment. In the benchmark model, we proxy S_t by the Euro Stoxx volatility index (VSTOXX). In Section 7, we check the robustness of our results for alternative proxies for market sentiment. There we also consider a specification in which economic policy uncertainty is included as a sentiment variable, instead as one of the fundamentals in MF_t, to test to what extent this variable captures the general market sentiment.

The response of investors (and thus spreads) to macro-fundamentals is likely to be different in stressed markets than in quiet conditions. Since we are primarily interested in this relationship under normal market conditions, we control for the

[5] The sovereign bank nexus is proxied by variable (exposure to domestic sovereign debt over total bank assets). Economic policy uncertainty is an index, which is published here.

interaction between MF_t and market sentiment (S_t) via the last term in the equation. Here we follow (Balli and Sørensen, 2013), who specify the interaction effect in demeaned terms. This specification makes coefficient vector β' the partial effect of macro variables on spreads evaluated at $S_t = \bar{S}$, with $\bar{S}$ being the average market sentiment in 2005-2022, reflecting normal financial market circumstances. This differs from the usual specification of the interaction effect (which would be $MF_t \cdot S_t$), in which case coefficient vector β' would measure the partial effect of macro variables on spreads evaluated at $S_t = 0$. However, the interaction effect in demeaned terms is our preferred specification, since we estimate the relation between MS_t and MF_t under normal market conditions (i.c. $S_t = \bar{S}$).

Since sovereign spreads reflect market expectations, we use the one year ahead Consensus forecast of the macro variables.[6] We include MS_t and MF_t in levels, based on tests that indicate that the variables are cointegrated (most variables have a unit root, see Annex 3). Monetary policy is not explicitly included on our regressors but likely to work through the explanatory variables in our equation – in Section 6 whether adding monetary policy variables affects our baseline results.

We investigated potential endogeneity between the moments of spreads and economic variables, as it is conceivable that a spread widening might cause negative feedback effects on economic fundamentals. However, endogeneity tests show that we cannot reject the null hypothesis that our economic variables are exogenous (see Annex 2). Hence, our first-stage regression is estimated with ordinary least squares (OLS).

In the second stage of our modelling approach, we use the estimated vector β' from the first stage to generate in-sample predictions of the model-implied moments of sovereign spreads ($\widetilde{MS}_t$), assuming $S_t = \bar{S}$. This implies that the effect of γ_t and λ_t' on MS drops out (the effect of γ_t drops out because the derivative of MS with respect to $\bar{S}$ is 0, while the effect of λ_t' drops out because $S_t = \bar{S}$ makes the interaction effect equal to 0). So $\widetilde{MS}_t$ is determined by the partial effect of the macro moments on spreads moments under normal market conditions. We interpret $\widetilde{MS}_t$ as the fundamentally justified moments of the spread distribution, implicitly assuming that

[6] The debt-to-GDP ratio is calculated by subtracting the expected one year ahead primary fiscal balance (which excludes interest payments) to the latest realisation of the debt level.

the impact of deviations of market sentiment its average level is not based on fundamentals. It could reflect fragmentation and may be a reason for the central bank to intervene. We compare the predicted moments $\widetilde{MS}_t$ with those of the observed spreads (MS_t). If the latter exceed the upper confidence band of $\widetilde{MS}_t$, spreads are likely excessive given the macro-economic fundamentals, indicating that sovereign bond markets are fragmented beyond differences in underlying fundamentals. So the deviation of $\widetilde{MS}_t$ from MS_t is our metric to identify unwarranted financial fragmentation.

Fig. 2 shows that spread moments show significant variation over time, while previous studies (e.g. De Grauwe and Ji, 2021; Eijffinger and Pieterse-Bloem, 2022) have documented that the impact of macro-fundamentals is likely regime-dependent. Therefore, we estimate our model with time-varying parameters – using a 60 months rolling window – as well as with fixed parameters. Time-variation can be due to, for instance, changes in the (global) economic or institutional environment or to regime changes. Such changes may affect a countries' creditworthiness (as reflected in sovereign spreads), even though the countries' macro-economic variables and market sentiment remain unchanged. The set-up of the European Stability Mechanism (ESM) in 2012 is an example of a change in EMU institutions that supports the creditworthiness of member states. For these reasons, the model with time-varying parameters is used as the baseline model for the estimation outcomes reported in the next sections.

5. Outcomes

Fig 3-5 present the observed moments of spreads MS_t as well as the model-implied moments $\widetilde{MS}_t$ for the time-variant model, while similar graphs for the fixed parameter models are presented in Annex 4. There have been several occasions where the actual spread moments exceeded the upper bound of the model-based benchmark, which would be an indication of non-fundamental spread widening or fragmentation. In general, time varying parameters track the fluctuations in the spread moments more closely than fixed parameters, implying that deviations from the model-based benchmark are smaller for smaller windows. This is further confirmed by a sensitivity test in which we estimate the model with a rolling window of 72 instead of 60 months.

By lengthening the window to 72 months, the deviation of MS_t from $\widetilde{MS}_t$ increases. This illustrates the sensitivity for the model specification, which is a general finding in related studies.

Around 2010, *skew* and *kurt* exceed the model-based range of the fixed-parameter model, while *stdev* remains close to – or even below – fundamental values. For the time-varying model, *stdev* is a borderline case and the other measures are within the range. Altogether, this presents some evidence for fragmented markets when the European debt crisis started and the ECB launched its SMP asset purchase programme to stabilize markets of vulnerable economies. But the evidence is ambiguous, which implies that other indicators would have to be considered as well, and that the crisis may have been largely driven by fundamentals that would require a more comprehensive response of policymakers than only central bank interventions.

In 2012, especially *stdev* exceeds the model-predicted range, both for the time-varying and the fixed-parameter models. The *skew* also rises significantly while *kurt* remains inside the range defined by fundamentals. This suggests that spread differentials were driven by non-fundamental factors in the 2012 sovereign debt crisis. Hence, our metric provides evidence that sovereign debt markets were fragmented during this episode. With hindsight, this justifies the announcement of the OMT programme, which was aimed at fragmentation and succeeded in normalizing spreads.

In the first half of 2015, the observed moments MS_t again exceed the upper bound of model-implied moments ($\widetilde{MS}_t$), particularly for the fixed parameter model. This reflects the impact of the financial crisis in Greece, culminating in a default on its IMF loan, a deadlock in the negotiations with official creditors and the introduction of capital controls in June 2015. The overshooting of *skew* and *kurt* indicate that the Greek crisis was associated with non-fundamental factors driving the distribution of observed sovereign spreads of EMU countries.

Since 2018, the moments of the observed spread distribution MS_t have hardly exceeded the upper bound of the model-implied moments $\widetilde{MS}_t$. This indicates that there has been no fragmentation across EMU countries and that spread differences mostly reflect in differences in macro-economic fundamentals. Rather, the observed spread moments have often been *below* the model-implied range, which would point at a lack of differentiation in risk pricing on financial markets. This is most obvious for *skew* and *kurt*. It may reflect that investors assume that the default risk of countries with the weakest fundamentals (either a cluster of countries as reflected in *skew*, or an outlier as reflected in *kurt*) is lower than the fundamentals indicate, possibly because they count on central bank backstop facilities. Recent research indicates that investors attach value to these kind of backstops for tail risk in sovereign bond markets (Broeders et al., 2022).

The COVID-19 pandemic did not lead to an increase of observed and model-implied increases in the spread moments in 2020-2021. This may be attributed to the fact that the pandemic was a common shock hitting all EMU economies in a similar way. As a result, dispersion, skewness and kurtosis of the distribution of macro-fundamentals in general did not rise (Annex 5). Only the *stdev* of the public debt ratio increased substantially mid-2020, but higher moments of other variables even hit multi-year lows in the pandemic period (such as *stdev* of GDP growth, *skew* of current account balance and policy uncertainty, *kurt* of inflation).

Like other central banks, the ECB immediately reacted to the COVID crisis with large-scale interventions that were motivated by the worsening economic outlook as well as rising market turbulence. This swift policy response, which included the flexible Pandemic Emergency Purchase Programme (PEPP) that could differentiate between EMU member states, may have prevented fragmentation of sovereign debt markets. This is in line with the finding of De Grauwe and Ji (2021), who conclude that the willingness of the ECB to act as lender of last resort in sovereign bond markets reduced the fragility of EMU countries.

The energy crisis in 2022 is reflected by a rise in *stdev, skew* and *kurt* of GDP growth, inflation, current account balance and policy uncertainty (Annex 5). This suggests that the energy shock had asymmetric effects on EMU countries, related to their different vulnerabilities to the shock and their dependency on Russian gas in particular. This shows up in an increase of model-implied dispersion, particularly as measured by *stdev* in 2022. The moments of the distribution of observed sovereign spreads (MS_t) also increased somewhat, but remained at or below model-implied level ($\widetilde{MS}_t$), implying that there was no fragmentation.

Since the start of the monetary policy hiking cycle in July 2022, the model-implied *skew* and *kurt* have increased somewhat. However, the observed moments of the spread distribution remained within or even below the model-implied ranges. This indicates that the policy rate hikes (and the discontinuation of net asset purchases) by the ECB since mid-2022 did not lead to unwarranted fragmentation. This may partly be attributed to the presence of ECB backstop facilities, in particular the PEPP and the TPI. These programmes are available to counteract financial fragmentation through asset purchases.

Figure 3, Predicted and observed stdev sovereign spreads (rolling window)

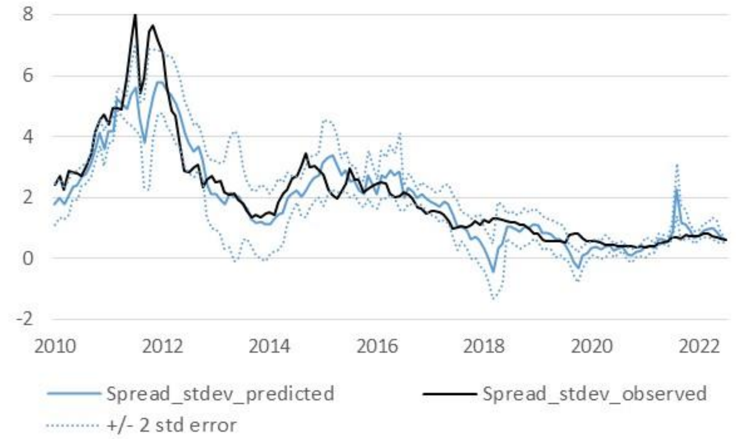


Figure 4, Predicted and observed skew sovereign spreads (rolling window)

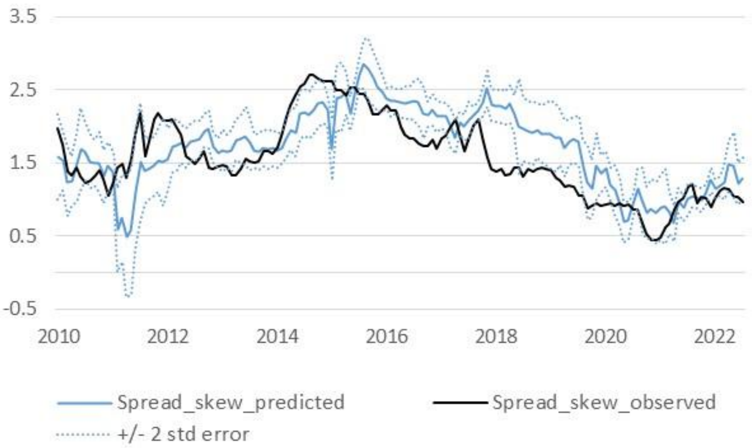
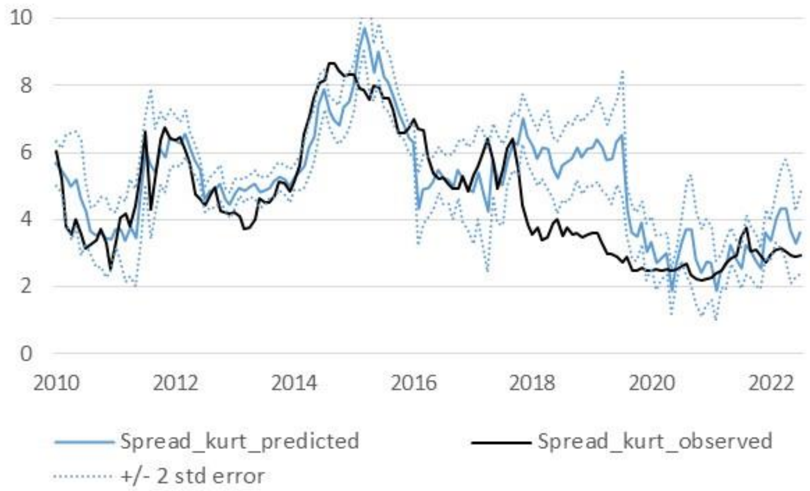


Figure 5, Predicted and observed kurt sovereign spreads (rolling window)



Note: results of regression model with 5 years (60 months) moving window

6. Monetary policy

The baseline model in the previous section does not include monetary policy variables, although these are likely to play a role through their impact on macro-economic variables. In this section, we further investigate the role of monetary policy variables by explicitly considering their impact on the regression outcomes. We do this in three ways. First, we test to what extent the deviation of the observed spread moments from the model-implied moments can be explained by the announcement of ECB asset purchase programmes. Second, we add Target2 balances, which have been an important consequence of monetary policy since the global financial crisis, to the model and test whether this improves the model fit. Third, we estimate the impact of monetary policy shocks on the *stdev*, *skew* and *kurt* of sovereign spreads with a local projections model.

6.1 Announcement effects of asset purchase progammes

In this section, we test to what extent the deviation of the observed from the model-implied moments of the spread distribution can be explained by ECB asset purchase programmes. More specifically, we consider the four purchase programmes of sovereign bonds aimed at market stabilization (SMP, OMT, PEPP, TPI) that were announced in our sample period.[7] We conduct a t-test on the means of the observed and model-implied moments of spreads, both for a horizon of 3 and 6 months after the announcement (and for the full sample period as cross-check). We also include one month before the announcement to take into account possible anticipation effects. So the t-test has two windows: [-1,3] and [-1,6]. Table D in Annex 3 shows that the null hypothesis (means of observed and model-implied moments are equal in the sub-sample periods around the announcements) is rejected for for *kurt* in the fixed parameter regression and for *stdev* in the time varying parameter regression (the preferred model specification, while *stdev* is the most robust distribution moment given small sample concerns). This provides some partial evidence that the announcement of asset purchases by the ECB, aimed at stabilizing bond markets, might be a separate explanator of the deviation between the observed and model-implied moments of spreads.

6.2 Target2 balances

Another test for the influence of monetary policy is by including the higher moments of Target2 balances in the model. Target2 balances are intra-Eurosystem claims on the balance sheets of national central banks and the ECB, resulting from accumulated cross-border payments in central bank reserves, which are settled via the Target2 payment system (Eisenschmidt et al., 2017). The increase in Target2 balances has been facilitated by the creation of excess reserves due to the Eurosystem's large-scale asset purchases and lending operations. In stress situations, an increase in Target2 balances may reflect increasing fragmentation across EMU countries, which has been one of the motivations for unconventional measures. This makes the Target2 balances a useful control variable in the model, as it reflects one aspect of the ECB's interventions: to address market dysfunction and excessive spread movements. This aspect is particularly relevant in turbulent financial markets. In normal market conditions, however, the Target2 balances mainly reflect the liquidity creation by asset purchases and lending operations that are conducted to steer the monetary stance.

[7] We do not include private sector bond purchase programmes (targeting covered bonds, asset-backed securities and corporate sector securities) because we focus on sovereign spreads.

The moments of Target2 are added to the model specified by Eq.(1) as a fundamental variable, as part of vector MF_t of fundamental variables. This assumes that investors take into account the liquidity supply by the central bank as a structural determinant for the distribution of sovereign spreads. The moments of Target2 are interacted with market sentiment (S_t), similar to the moments of the other macro variables. Table E in the Annex 3 shows that the model fit becomes slightly better for some specifications if Target2 is added as variable: the root mean square error (RMSE) is slightly lower for the fixed-parameter specification of all three moments (*stdev*, *skew*, *kurt*) compared to the benchmark model (Table C). For the varying-parameter specification, the baseline specification without Target2 performs slightly better in two of the three cases (*stdev*, *kurt*) while in one case (*skew*), adding Target2 improves the fit.

Because of these mixed results, and the fact that differences in fit are small, the impact of adding Target2 balances seems limited. The explanation for this result is that before the start of QE in 2015, Target2 balances were mainly determined by lending operations aimed at bank funding and less at the stabilization of sovereign bond markets, while in the QE period the Target2 balances primarily reflect the increased reserve supply related to the monetary stance. It should be noted that the estimated contribution of Target2 is estimated as an average contribution over the whole sample period, whereas the t-test outcomes in the previous section focus on the sub-sample periods in which the ECB announced asset purchase programmes.

6.3 Effects of monetary policy shocks

We estimate the impact of monetary policy shocks on the *stdev*, *skew* and *kurt* of sovereign spreads with local projections, following Jorda (2005). The local projection model is specified by the following equation,

$$MS_{t+h} = \alpha_t + \varphi\, MP_t + \beta_0'\, MF_t + \beta_1'\, MF_{t-1} + \gamma S_t \; + \varepsilon_{t+h} \qquad (2)$$

Where MS_{t+h} refers to the moments of sovereign spreads in period $t+h$; with $h = 0, 1, 2, \ldots\ H$ the projection horizon, set to 12 months. MF_t is the vector of moments of the distribution of macro-economic variables *1...j* and S_t the market sentiment variable. Both MF_t and S_t control for the influence of other factors than monetary policy and are the same variables as included in Eq.(1). All variables are included in first differences. Variable MP_t is the monetary policy shock variable, for which we use different proxies;

- The 3 month money market rate (MP^m);
- The 10 years OIS rate (MP^y);
- The expectations (MP^e) and term premium component (MP^t) of the 10 years OIS rate (constructed by a term structure model[8]).

These variables capture (expected) changes in monetary policy as priced in by financial markets.

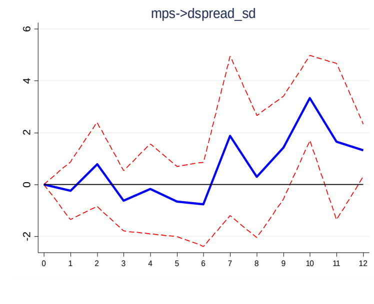
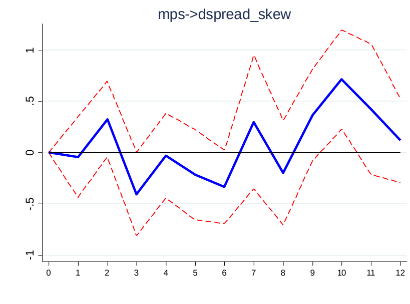
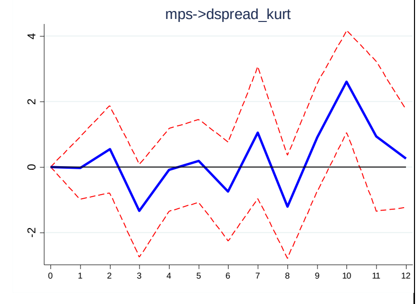
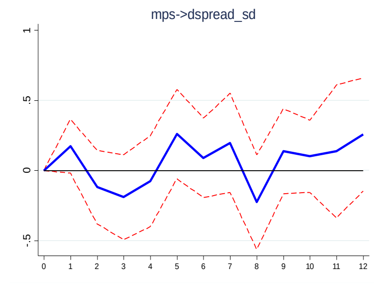
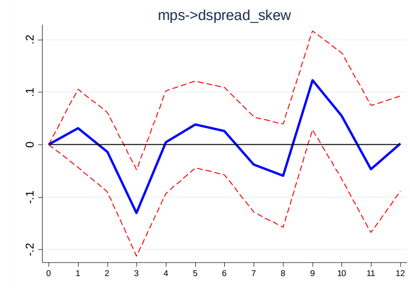
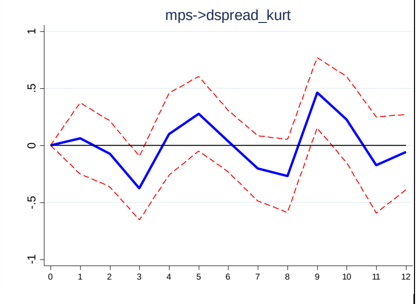
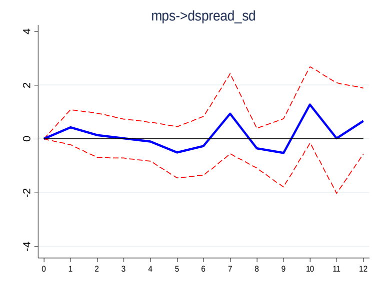
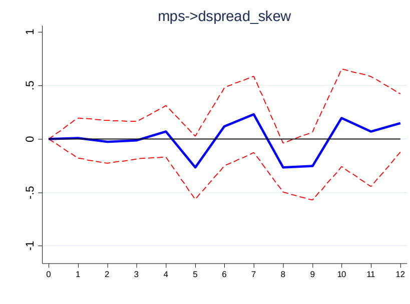
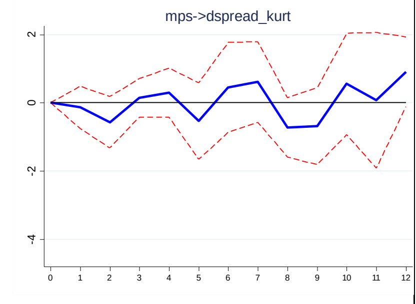
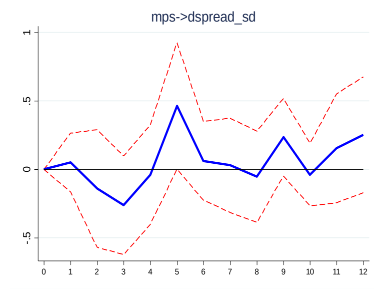
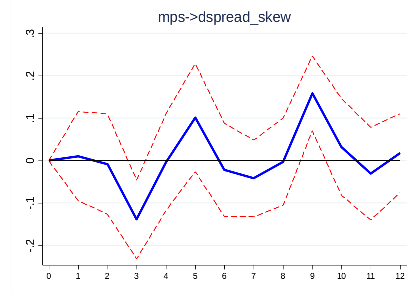
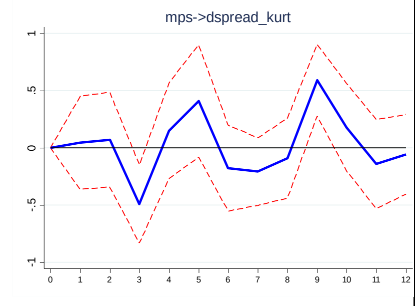
To take into account possible endogeneity between monetary policy and sovereign spreads, we use monetary surprise shocks as an alternative in Eq.(2). These are taken from Altavilla et al. (2019), who construct series for policy rate shocks and QE shocks. These shocks are based on factors extracted from changes in yields of risk-free rates at different maturities in a short window around ECB press statements. The first factor (MP^r) has a high loading on short term market interest rates and so captures surprise shocks in the policy interest rate. The second factor (MP^q) has a high loading on long-term bond yields and so reflects surprise shocks in QE measures.

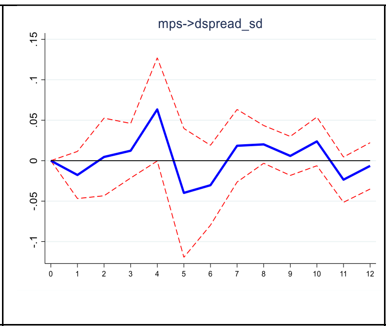
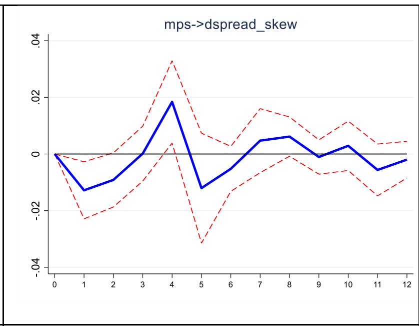
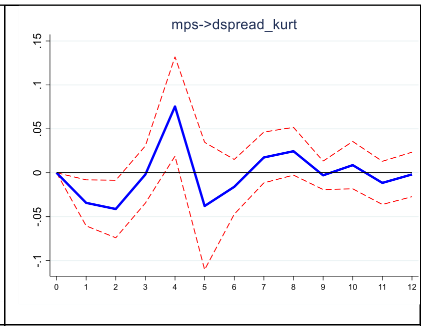
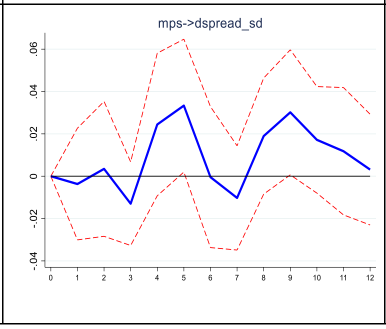
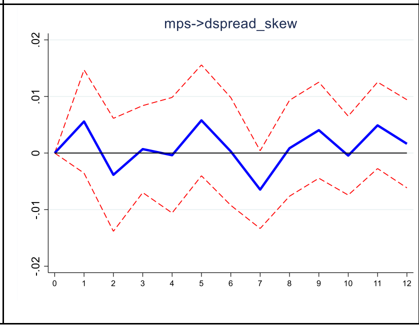
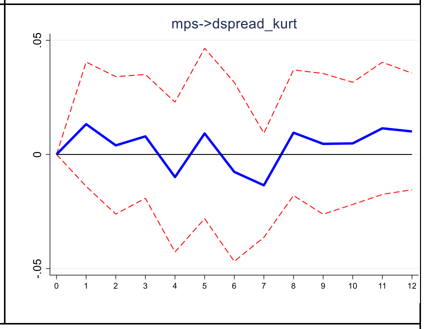
We restrict the sample to 2010m4-2023m2, when monetary policy was occasionally aimed at limiting fragmentation in sovereign bond markets.[9] Figure 6 shows the results of the impulse responses of the local projections model, i.e. the response of *stdev*, *skew* and *kurt* to a one standard deviation shock in the monetary policy variable. A positive sign of the impulse response of the spread moments means that an expansionary monetary policy shock leads to a decrease of *stdev*, *skew* and *kurt*, while a tightening leads to an increase in the spread moments. This is the expected sign of the responses, assuming that the ECB intervenes to reduce financial fragmentation. Nearly all impulse responses are statistically insignificant, also when the model is estimated over the full 2005m1-2023m2 sample period. This suggests

[8] The yield components are estimated with an arbitrage-free short-rate based multiple factor model, combining Nyholm (2018) with Christensen, Diebold and Rudebusch (2011).
[9] The main stabilization policies aimed at sovereign debt markets that have been announced in this period are the SMP (2010), the OMT (2012), PEPP (2020) and the TPI (2022).

that monetary policy shocks did not have a noticeable effect on financial fragmentation. This could be explained by the fact that monetary policy was in most of the period aimed at the monetary stance and only occasionally on market stabilization.

Figure 6.
Impulse responses to 1 standard deviation shock in (i) MP^m, (ii) MP^y, (iii) MP^e, (iv) MP^t, (v) MP^r, (vi) MP^b

	A. Stdev	*B. Skew*	*C. Kurt*
i. Money market rate (MP^m)			
ii. OIS 10 yr (MP^y)			
iii. Expectations comp. (MP^e)			
iv. term premium (MP^t)			

v. Policy rate surprise (MP^r)			
vi. QE surprise (MP^q)			

Notes: Figure 6 presents the estimation results using local projections to assess the impact of monetary policy shocks on the moments of the sovereign spread distribution. The results are based on Eq.(2), estimated for 2010m5 - 2023m2. The red dotted lines are the 90% confidence intervals. The number of months is shown on the x-axis. The y-axis shows the impulse responses in percentage points. The variables are included in first differences.

6.4 Summary

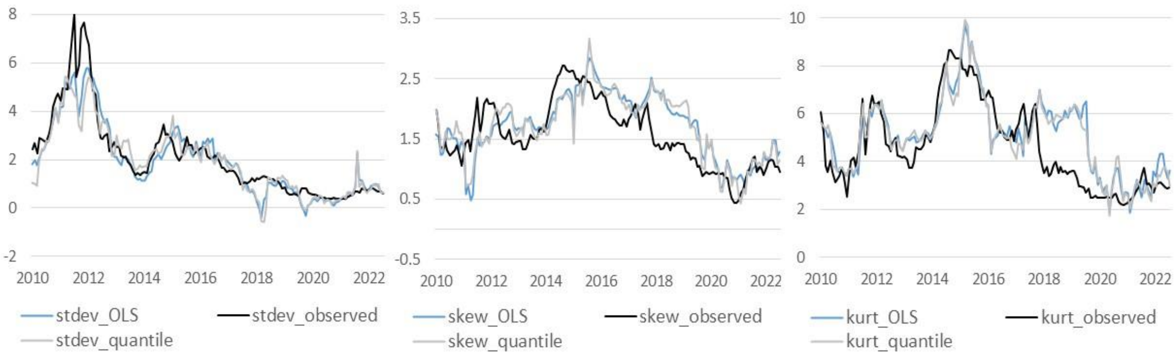
Altogether, it is difficult to find a direct impact of monetary policy variables on higher moments of sovereign spread distributions. Perhaps the most concrete evidence is the effect of announcements of stabilization programmes reported in Section 6.1. The Target2 balances can improve the model fit, but this result reported in Section 6.2 is only found for the (less robust) *skew* and *kurt* indicators and for the fixed-parameter model, while the most preferred combination (*stdev*, time-varying) leads to a deterioration of the fit. Nearly all of the impulse-responses of the local projections model are statistically insignificant.

Besides these outcomes, it should be noted that monetary policy may play an indirect role in our baseline result, through its impact on macro-economic variables that are included as one-year ahead expectations. These expectations may incorporate expectations about monetary policy, amongst other factors. Beyond this possible indirect impact, particularly the announcement of stabilization programmes targeting sovereign debt market seems to have an additional, more direct impact.

7. Robustness tests

To check for the difference between the model estimations based on the mean and the median of the response variable (i.c. the moments of sovereign spreads), we estimate the model based on quantile regressions as a robustness test. Quantile regression estimates are more robust against outliers in the response variable. We estimate the conditional median of response variable MS_t based on Eq.(1). The outcomes in Figure 7 show that the model-implied moments predicted by the quantile regression ($\widetilde{MS}_t^q$) are quite similar to the moments predicted by OLS ($\widetilde{MS}_t$). Occasionally, the deviations of the observed moments from $\widetilde{MS}_t^q$ are somewhat larger than from $\widetilde{MS}_t$. This reflects that $\widetilde{MS}_t^q$ does not fit with the outliers in MF_t, given that $\widetilde{MS}_t^q$ is the conditional median moment of sovereign spreads. It implies that deviations from the observed moments are enlarged by construction, which makes the quantile regression approach less suitable as baseline.

Figure 7, Predicted and observed moments of sovereign spreads (rolling window)



In another robustness test we use alternative variables for market sentiment in the rolling window estimations. We replace VSTOXX by the Treasury bond market volatility index (MOVE) and estimate the model for the standard deviation (*stdev*) of spreads as an illustration. The outcome shows that the observed spread moments (MS_t) deviate more from the model-implied moments ($\widetilde{MS}_t$) with MOVE instead of VSTOXX as sentiment variable (S_t), see Annex 6, panel A.1. Particularly in the 2012 sovereign debt crisis, fragmentation is more evident with MOVE as sentiment variable.

Next we assume that economic policy uncertainty is not a fundamental variable (part of vector *MF*) but a variable for market sentiment (*S*). This robustness test takes into account that economic policy uncertainty might capture similar information as VSTOXX. The estimation outcome shows that if we include economic policy uncertainty instead of VSTOXX as sentiment variable (S_t) the observed *stdev* of spreads (MS_t) deviate more from the model-implied *stdev* ($\widetilde{MS}_t$). Particularly in the 2012 sovereign debt crisis, fragmentation is more evident with economic policy uncertainty as a sentiment variable (Annex 6, panel A.2). Including economic policy uncertainty as sentiment variable (instead of fundamental) reduces the fit of the model (RMSE = 0.98) compared to the specification with economic policy uncertainty as fundamental and VSTOXX as sentiment (RMSE = 0.81 see Table F in Annex 3). This indicates that VSTOXX has additional explanatory power as sentiment indicator beyond economic policy uncertainty.

8. Conclusions

We present an area-wide fragmentation metric, providing a single measure for each moment of spread distribution across time. So we exploit both the cross-country dimension and the cross-time dimension of financial fragmentation. Typically, crises are associated with increasing spread dispersion, more skewness and fatter tails. In that context, the distribution moments we consider show a plausible pattern as they are related to crisis episodes as well as central bank policy interventions. At the same time, the three moments of the sovereign spread distribution are complementary as they contain their own, specific information about sovereign credit risk.

The value-added of our metric is that it provides a single, area-wide measure of fragmentation, which exploits the cross-country and cross-time information contained in the higher moments of sovereign spreads. It would supplement existing approaches that typically focus on spreads of individual countries relative to fundamentals (but could miss the overall picture) and high-frequency developments that could provide a first signal (but are harder to control for fundamentals). Our metric could be part of a suite of indicators, which also cover country-specific and high-frequency indicators.

The metric shows that most of the time, the higher moments of the sovereign spread distribution can be explained by the moments of macro-financial fundamentals. The main exceptions are time intervals in 2012 (euro area debt crisis) and 2015 (Greek default), when our model is unable to fully explain the rising dispersion in spreads. With hindsight, the deviation of observed from the model-implied moments of sovereign spreads in 2012 justified the announcement of the OMT programme by the ECB. Test outcomes confirm that occasionally monetary policy decisions – particularly the announcement of stabilization programmes – contribute to explain the moments of the sovereign spread distribution. Since 2018, the moments of observed spreads have generally not exceeded thefundamentals-based moments, also not in the most recent period, despite the increase in interest rates. This may be partly attributed to ECB backstop facilities, such as the PEPP and TPI programmes, which underlines findings in the literature that the willingness of the ECB to act as lender of last resort in sovereign bond markets has reduced the fragility of EMU countries.

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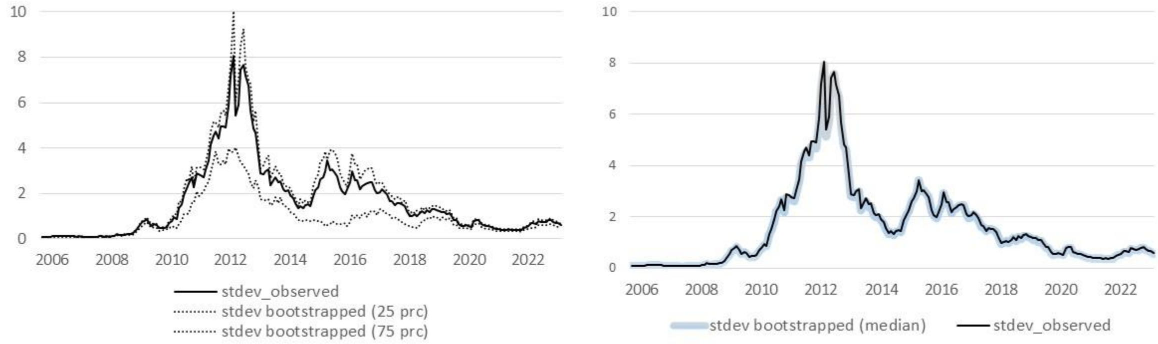
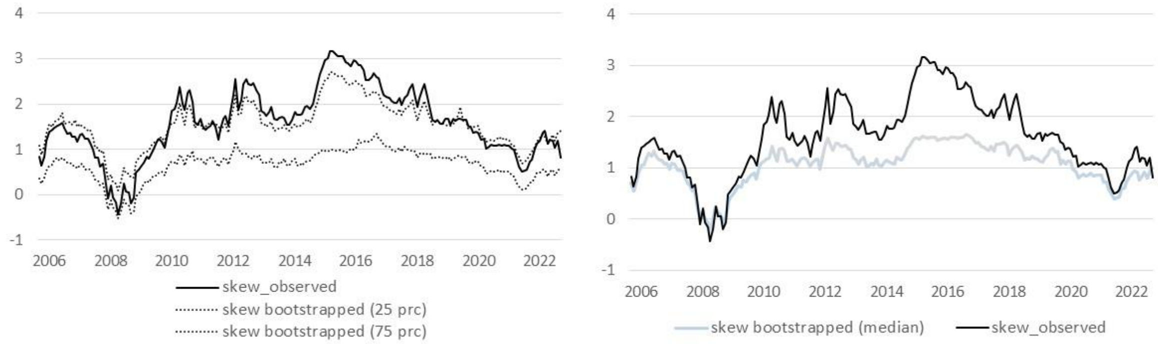
Annex 1. Bootstrap analysis

Figure A. Observed and bootstrapped spread moments

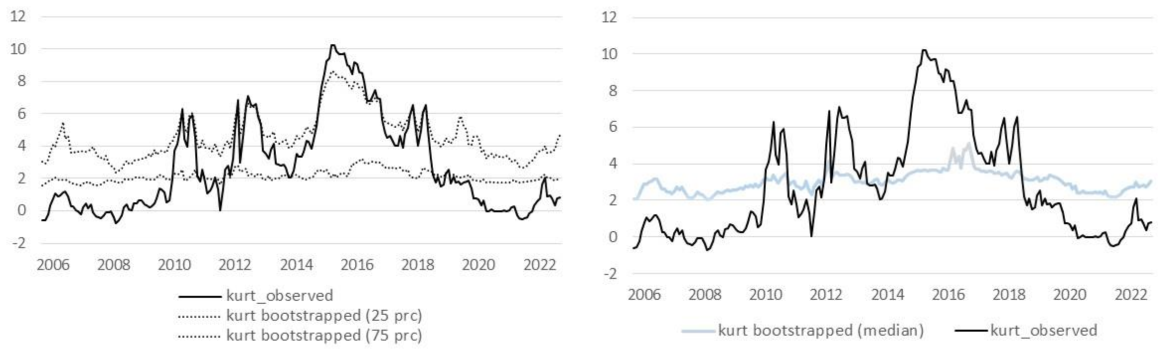
Panel A.1. Stdev (Interquartile range in left panel. Median in right panel)



Panel A.2. Skew (Interquartile range in left panel. Median in right panel)



Panel A.3. Kurt (Interquartile range in left panel. Median in right panel)



Annex 2. Endogeneity tests

We investigate potential endogeneity of our main economic variables, as it is conceivable that these are affected by our dependent variable (spreads) rather than the other way around. To investigate this, we performed two-stage least squares (2SLS) regressions, assuming that (moments of) GDP growth, inflation, the current account and the debt ratio are endogenous and using one and two quarter lags of these variables as instruments.

We first test whether these instruments are sufficiently related to the (assumed) endogenous variable, using the Kleibergen-Paap rk LM test (underidentification) and the Cragg-Donald F tests (weak instruments). Adequate instruments require the null hypothesis to be rejected, which is clearly the case for the underidentification test in all three specifications. For the weak instrument test, we do not have critical values but rely on the rule-of-thumb that the F statistic should be larger than 10, which is the case for all three specifications.

Second, we check whether the instruments are uncorrelated with the error terms, testing overidentifying restrictions with the Hansen J statistic. The null hypothesis is that overidentifying restrictions are valid, which can not be rejected in all three cases.

Finally, we test whether GDP growth, inflation, the current account and the debt ratio are indeed endogenous. This is done with a chi-squared test, where the null hypothesis is that the instruments are exogenous. The null cannot be rejected, implying that the variables may be considered exogenous.

Overall, using relevant and valid instruments to investigate endogeneity of our economic fundamentals, we find no evidence that these variables are indeed endogenous. Hence, in the main text we apply ordinary least squares as this is likely to yield more efficient results than instrumental variables regressions. Using instrumental variables (2SLS) yields very similar results, however, and would not lead to different conclusions.

Table A *Tests of instrumental variables and endogeneity*

	Moment		
Test statistics	**Stdev**	**Skew**	**Kurt**
Underidentification / weak instruments:			
Kleibergen-Paap rk LM statistic	50.85 (0.0000)	54.26 (0.0000)	46.06 (0.0000)
Cragg-Donald F statistic	44.09	38.14	61.75
Overidentification / exogeneity of instruments:			
Hansen J statistic	7.63 (0.1043)	1.09 (0.8956)	4.75 (0.3140)
Endogeneity test of endogenous regressors:			
Chi-square test	5.83 (0.2121)	2.31 (0.6786)	6.44 (0.1687)

Annex 3. Statistical tests

Table A. Unit root tests

Augmented Dickey-Fuller test (1 lag)

	stdev	*skew*	*kurt*
Sovereign spread	-1.78	-2.09	-2.19
Debt ratio	-1.30	-2.10	-3.47**
GDP growth	-2.21	-1.74	-3.12**
Inflation	-3.60***	-3.12**	-3.39**
Current account	-0.95	-0.59	-0.48
Policy uncertainty	-2.91**	-7.57***	-8.41***
Sovereign/bank nexus	-0.12	-1.76	-1.99

Test statistc; ***, **, * denote rejection of unit root hypothesis at 1%, 5%, 10% significance level.

Table B. Cointegration tests

Cointegration tests (1 lag)

	stdev	*skew*	*kurt*
Augmented Dickey-Fuller test	H0: no cointegration ***	H0: no cointegration	H0: no cointegration**
Johansen test	H0: no cointegration**	H0: no cointegration**	H0: no cointegration**

***, **, * denote rejection of H0 (no cointegration) at 1%, 5%, 10% significance level.

Table C. Root mean square error (RMSE) of the two regression models

	stdev	*skew*	*kurt*
Rolling window	0.69	0.42	1.22
Fixed parameters	0.78	0.50	1.19

Table D. T-test for mean difference between observed and model-implied spread moments in windows around announcements of market stabilization programmes

	stdev	skew	kurt
	Rolling window		
window			
[-1, 3]	0.00 ***	0.12	0.50
[-1, 6]	0.02 **	0.35	0.99
Full sample	0.00 ***	0.00 ***	0.00 ***
	Fixed parameters		
[-1, 3]	0.87	0.60	0.08 *
[-1, 6]	0.60	0.78	0.00 ***
Full sample	0.61	0.50	0.26

P-values, ***,**,* denote rejection of H0 (equal means) at 1%, 5%, 10% significance level.
Paired sample, two-tailed T-test.

Table E. Root mean square error (RMSE) of model estimations including Target2

	stdev	*skew*	*kurt*
Rolling window	0.73	0.36	1.25
Fixed parameters	0.76	0.49	1.16

Table F. Root mean square error (RMSE) of model estimations for stdev with alternative sentiment variables

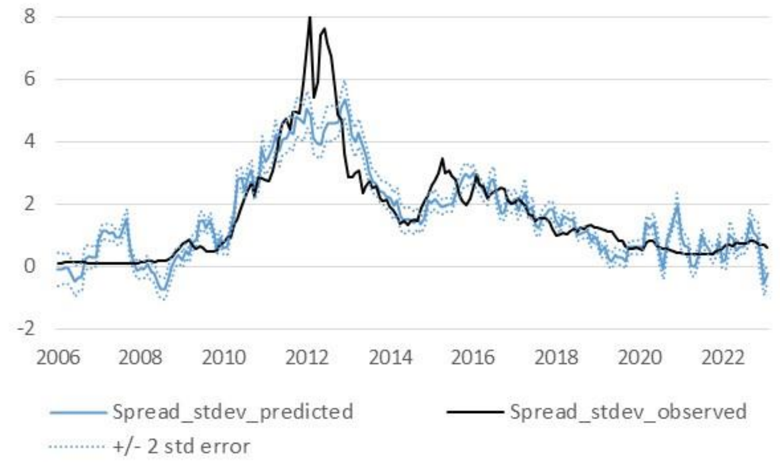
	Variable for sentiment (S)		
	*VSTOXX**	*MOVE**	*POL*
Rolling window	0.69	0.83	0.88

* Economic policy uncertainy included as fundamental

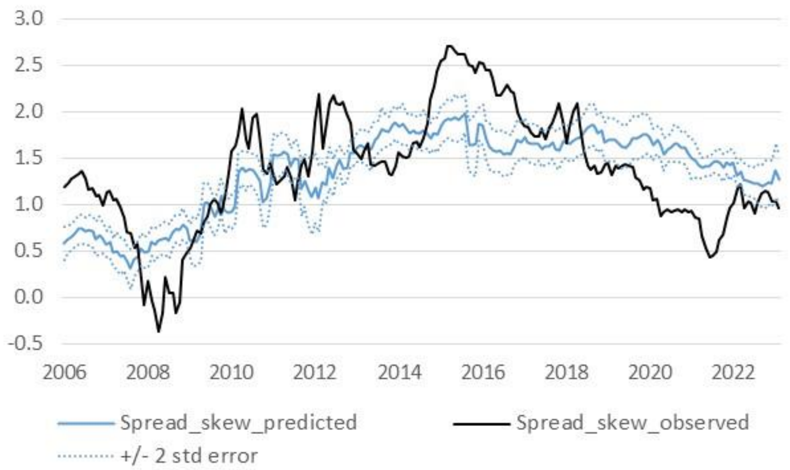
Annex 4. Outcomes of fixed parameter model

Figure A. Outcomes of fixed parameter regressions

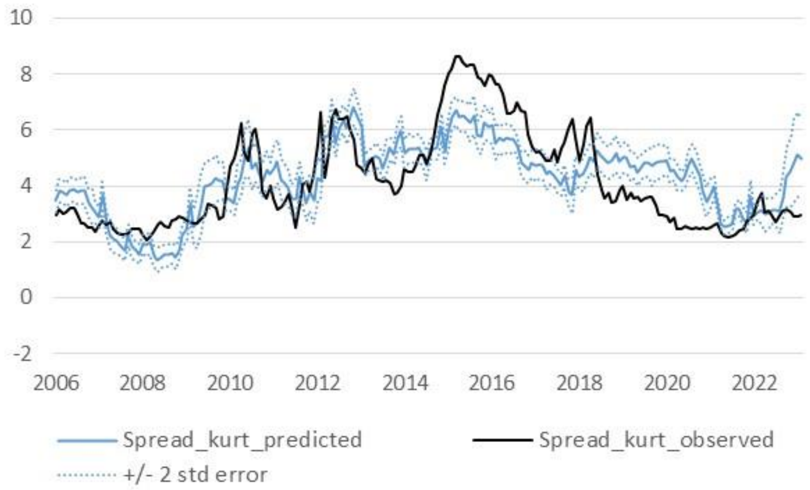
Panel A.1. Predicted and observed stdev sovereign spreads (fixed parameters)



Panel A.2. Predicted and observed skew sovereign spreads (fixed parameters)



Panel A.3. Predicted and observed kurt sovereign spreads (fixed parameters)



Annex 5. Moments of macro-economic variables

Figure A. Higher moments of the distribution of macro variables of EMU countries

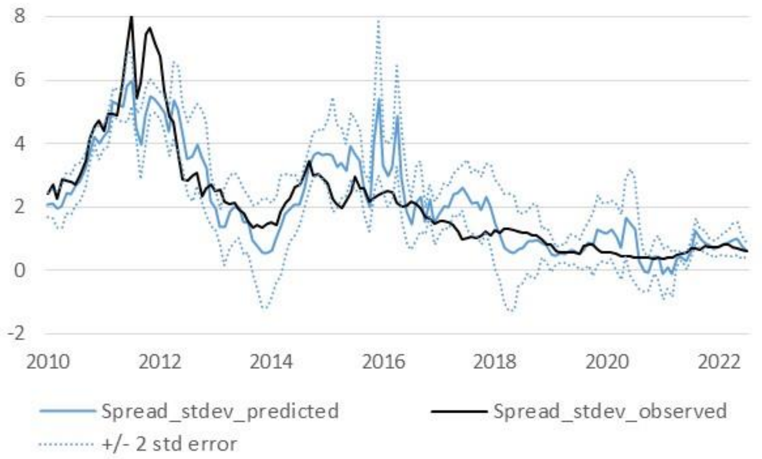
Panel A.1. Standard deviation

Panel A.2. Skewness

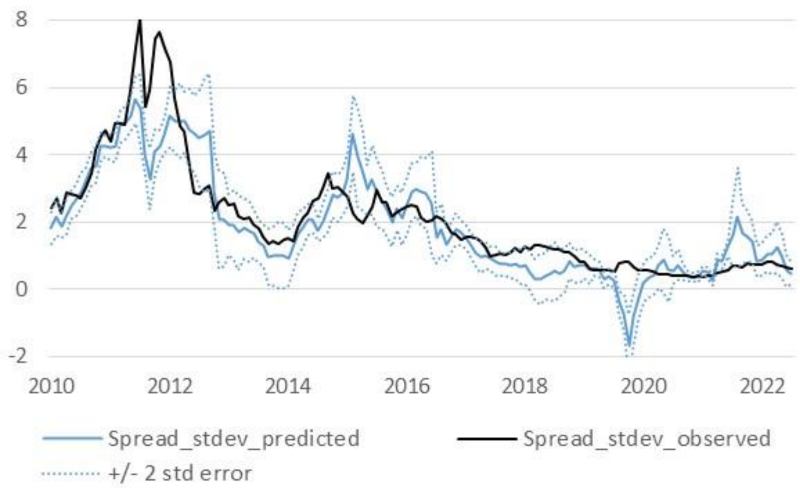
Panel B.3. Kurtosis

Annex 6. Robustness tests

Panel A.1. Robustness test: predicted and observed stdev sovereign spreads, with MOVE as sentiment variable (rolling window)



Panel A.2. Robustness test: predicted and observed stdev sovereign spreads, with economic policy uncertainty as sentiment variable (rolling window)



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