Financial contagion in the eurozone

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Abstract
We study financial contagion in the euro area stock markets during the European sovereign debt crisis. We look at both stock returns and volatility measures extracted from option prices. We also provide measures of excess dispersion and correlation by combining data on stock indices and their constituents. We find higher correlations for volatilities than returns. We also find that return correlations increase in volatile periods. The impact of the crisis across countries and sectors, however, was heterogeneous. Banks were mostly affected, those from core countries holding Greek bonds first, and Spanish and Italian banks holding mostly domestic sovereign debt later.

Keywords: Correlation, Dependence, Financial derivatives, Stock markets, Tail risk, Volatility

JEL: G15, G01, F65

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1 Introduction

Financial crises are not a modern phenomenon, but their incidence, and especially the extent to which they have gone from being a domestic problem to a regional one, and more recently, a truly global concern, is definitely a sign of our times. This largely undesired globalisation of financial crises is intimately related to the concept of contagion. By analogy to the epidemiological concept of communicable disease, financial contagion literally means that the economic and financial difficulties in a country get fairly quickly transmitted to other more or less closely linked economies. The 1982 Latin America debt crisis, the 1994 Mexican peso “tequila” crisis, the 1997 Asian financial crisis, the 2007-2008 global financial crisis and the 2010-2012 European sovereign debt crisis are obvious examples of this phenomenon. Although several authors have developed detailed narratives for each of them, all those crises share an important characteristic: they typically start in a single country but they rapidly spread to others, even though the direct economic and financial links between the original country and some of the affected ones are fairly weak. For that reason, financial contagion at such a grand scale has been a fundamental driving force behind financial regulation, both at the domestic level and at the international one.

Nevertheless, the academic definition of contagion is not necessarily the same as the informal definition used by the media and the national and international financial regulators. Two stylised facts that have been noted before are that (i) there are certain periods when markets seem to move in unison and others when the correlation between them appears to be low; and (ii) periods when markets are increasingly correlated are also times when markets are volatile (see King and Wadhwani (1990) and Roll (1989) for some early evidence). Indeed, King and Wadhwani (1990) argued that this might be because a rise in volatility might lead agents to pay greater attention to other markets. Using a multivariate conditional heteroskedastic multifactor model for stock returns, King, Sentana and Wadhwani (1994) confirmed both the time-varying nature of correlations and the fact that periods of high volatility in the common global risk factors are also periods of increased correlation across national stock markets, which in turn substantially reduces the gains from international diversification. But these correlation increases cannot be really called contagion. For that reason, most previous approaches to identify real contagion episodes have started from a multifactor model for returns (see Dungey et al (2005) for a survey, with special emphasis on methodological aspects). According to Forbes and Rigobon (2002), contagion would then arise if and only if there is a “significant increase in cross-market linkages...
after a shock to an individual country or group of countries”.

The term cross-market linkages is particularly apt in this context because correlations only provide a complete description of dependence under multivariate normality. As we illustrated in early research with data from Global Systematically Important Banks from the Eurozone, stock returns display considerable non-normality even after controlling for time-varying volatilities and correlations, which in turn gives rise to the type of non-linear dependence that is relevant for systemic risk measurement (see Amengual, Fiorentini and Sentana (2013)). Models with multivariate asymmetric distributions seem particularly relevant from an empirical perspective given that tail dependence is usually stronger for falls in prices than for increases.

The literature on financial contagion has focus almost exclusively on stock returns. Nevertheless, stock returns on their own are not necessarily informative enough about tail dependence between financial markets, the reason being that by definition such simultaneous events only occur occasionally. As recently illustrated by Andersen, Fusari and Todorov (2016, 2017), financial derivatives in general, and out-of-the money put options, in particular, contain a lot of information about the left tail. For that reason, we combine data on several national stock market indices with options written on them. In that regard, our approach is related to the literature on risky debt, both corporate and sovereign, which has successfully combined data on bond yields with data on credit default swaps (CDSs) to increase our knowledge of default risk and loss given default, and the common movements in credit ratings observed in practice (see e.g. Pan and Singleton (2008) or Duffie et al (2009)).

In this paper, we focus on the most recent example of contagion: the European sovereign debt crisis, paying particular attention to Spain. A very important distinctive feature of this crisis is that it took place within a monetary union, whereby the countries involved shared a single currency. Although at some point in 2012 some commentators and financial market participants questioned the survival of the European monetary union (EMU), the crisis had no direct effect on the exchange rates across EMU countries, which had been fixed in 1999. This is in marked contrast to the financial crises that occurred in the 1990s, in which the effects on exchange rates were first order.

The rest of the paper is organised as follows. In the next section, we describe our data and discuss how we construct our volatility measures from option prices, and how we combine data on stock market indices and their constituents to obtain measures of excess dispersion
and correlation. Sections 3 and 4 employ our data and methodology to empirically explore the evolution of all those measures during the euro sovereign debt crisis. Our findings are followed by our conclusions and a data appendix.

2 Data and empirical methodology

We rely on daily data from the OptionMetrics Ivy DB Europe database for options on the following indices: the Euro Stoxx 50 (largest companies in the Eurozone), the BEL20 (Belgium), the CAC40 (France), the DAX30 (Germany), the FTSE MIB40 (Italy), the AEX25 (the Netherlands) and the IBEX35 (Spain). Although the Ivy database spans the period January 2002 to November 2016, the coverage is not homogeneous across securities. We also use data on options written on the individual stocks that are part of those indices. Finally, we combine the option data with prices of the underlying stocks/indices and index composition from Compustat.

All the aforementioned indices are value-weighted using free float market capitalization weights, with periodic rebalancing that often but not always takes place at the end of each quarter.\textsuperscript{1} Table 1 reports summary statistics about the total number of constituent companies over the sampling period, the number of them for which option data are available, and the rebalancing dates. Each time there is a change in the composition of an index, we reconstruct the index component weights using market capitalization based on stock prices and number of shares outstanding from Compustat. We keep these constituents fixed – and their number of shares outstanding – until the next rebalance date, but update the weights according to the daily stock price changes.\textsuperscript{2}

The list of securities corresponding to each index is selected mainly based on quote availability.\textsuperscript{3} Specifically, we compute the number of valid option quotes on each security in the sample period, and select the securities with the highest number of valid option quotes. To be consistent with the existing literature, we screened the data to eliminate those options with zero open interest or trading volume, or without a last trade in any given day. Further, we eliminated those observations with bid or ask prices smaller than €0.05 to mitigate the effect of

\textsuperscript{1}Occasionally, rebalancing occurs within a quarter, as after the recent liquidation of Banco Popular.

\textsuperscript{2}Nevertheless, our lack of data on the free float factors introduces a small discrepancy between the actual index daily weights and our computed weights. For the IBEX35, though, we obtained historical daily series of actual weights and changes in the index composition from Bolsas y Mercados Españoles.

\textsuperscript{3}There is a mismatch issue between Compustat and Optionmetrics that prevent us from considering all the firms appearing at any point in time in one of the indices. See Appendix A for the list of firms we exclude from our empirical analysis for that reason.
decimalization.

In the traditional Black-Scholes option pricing model with Gaussian diffusions, implied volatilities are constant across strikes and maturities. However, in practice, there are both smiles or smirks for a given maturity, and a term structure of implied vols for a given degree of moneyness. For that reason, we work instead with the so-called “variance swap rate”, which is the risk neutral expectation of the integrated variance for each index or individual stock for a given time-to-maturity. To compute it, we need observations across all strikes of out-the-money (OTM) options. As in Driessen, Maenhout and Volkov (2013), we select implied volatilities from calls with Black-Scholes (BS) deltas smaller than 0.5 and puts with deltas larger than −0.5 from the OptionMetrics’ Volatility Surface file. Then, we apply the methodology proposed by Bakshi, Kapadia and Madan (2003). Specifically, for stock/index i and time-to-maturity τ, we compute

\[
\tau \Sigma^2_{i,\tau}(t) = 2 \int_0^{S_i(t)} \left\{ 1 + \ln \left[ \frac{S_i(t)}{K} \right] \right\} P_i(t;\tau,K) dK + 2 \int_{S_i(t)}^\infty \left\{ 1 - \ln \left[ \frac{K}{S_i(t)} \right] \right\} C_i(t;\tau,K) dK, \tag{1}
\]

where \( S_i(t) \) denotes the price of stock/index i at time t, and \( P_i(t;\tau,K) [C_i(t;\tau,K)] \) the price at time t of a European put [call] option on \( S_i \) with strike K and time-to-maturity \( \tau \). To compute the integral that yields the desired value of the variance contract, \( \Sigma^2_{i,\tau}(t) \), we would need a continuum of option prices. In practice, we compute a discretised approximation to those integrals based on the available options. To do so, we linearly interpolate inside the available moneyness range, and extrapolate them by keeping the implied volatilities constant at the extremes. We use 121 grid points in the moneyness range from 1/3 to 3 (101 points within the available moneyness range, and 10 points at each extreme). Finally, we compute the integral (rectangle rule) using the Black-Scholes option prices from the interpolated volatilities.

As for correlations, we closely follow the methodology of the CBOE S&P 500 Implied Correlation Index. Specifically, under the assumption that the covariance structure of the returns on the index constituents is equicorrelated, which is an important special case of a single factor structure, the \( \tau \)-maturity implied correlation index can be obtained as

\[
\rho^Q_{\text{Index},\tau}(t) = \frac{\Sigma^2_{\text{Index},\tau}(t) - \sum_{i=1}^N w_i^2 \Sigma^2_{i,\tau}(t)}{2 \sum_{i=1}^{N-1} \sum_{j>i}^N w_i w_j \sqrt{\Sigma^2_{i,\tau}(t) \Sigma^2_{j,\tau}(t)}}, \tag{2}
\]

where \( \{w_i\} \) are the index weights and the superscript \( Q \) makes explicit the fact that this quantity is obtained under the pricing measure. In recent years, though, the numerator of (2), the so-called implied dispersion, has gained increased attention among both practitioners and researchers.
(e.g. Jones and Vischer (2015)). For that reason, in the empirical section we will consider both quantities separately. Although in theory the excess dispersion should always be non-negative and the implied correlation below 1, the indirect way in which we compute these quantities might occasionally lead to violations of those bounds.\footnote{The implied correlation for the S&P500 officially reported by the CBOE also exceeds 1 occasionally.}

Since we are also interested in cross-correlations within indices under the objective measure $\mathbb{P}$, we also use realized volatilities from OptionMetrics to construct the $\mathbb{P}$-measure analogous to $\rho^Q_{\text{Index},\tau}(t)$ for different horizons. To do so, we first compute the expected realized variance for each stock/index $i$ and maturity $t + \tau$ using an exponentially-weighted moving-average à la RiskMetrics (1996) with parameter $\alpha = 0.94$, say $E^\mathbb{P}_t[\int_t^{t+\tau} \sigma^2_{i,s} ds]$, where $\sigma^2_{i,s}$ is the volatility of asset $i$ over the next $s$ periods, so that

$$\rho^\mathbb{P}_{\text{Index},\tau}(t) = \frac{E^\mathbb{P}_t[\int_t^{t+\tau} \sigma^2_{\text{Index},s} ds] - \sum_{i=1}^N w_i^2 E^\mathbb{P}_t[\int_t^{t+\tau} \sigma^2_{i,s} ds]}{2 \sum_{i=1}^{N-1} \sum_{j>i}^N w_i w_j \sqrt{E^\mathbb{P}_t[\int_t^{t+\tau} \sigma^2_{i,s} ds]} \sqrt{E^\mathbb{P}_t[\int_t^{t+\tau} \sigma^2_{j,s} ds]}},$$

We also consider a third measure of correlation/dispersion, following most of the related literature, relying on realized variance as a proxy for $E^\mathbb{P}_t[\int_t^{t+\tau} \sigma^2_{i,s} ds]$ instead (see e.g. Driessen, Maenhout and Volkov (2009, 2013) or Faria, Kosowski and Wang (2016)).\footnote{Indeed, Driessen, Maenhout and Volkov (2013) point out that standard realized correlations are more commonly used than $\rho^Q_{\text{Index},\tau}(t)$ and that the difference between them is very small and not economically significant.} The corresponding average realized correlation is denoted by $\rho_{\text{Index},\tau}(t)$.

Finally, from the identity

$$E^Q_t \left[ \int_t^{t+\tau} \sigma^2_{\text{Index},s} ds \right] = \sum_{i=1}^N w_i^2 E^Q_t \left[ \int_t^{t+\tau} \sigma^2_{i,s} ds \right] + 2 \sum_{i=1}^{N-1} \sum_{j>i}^N w_i w_j \sqrt{E^Q_t \left[ \int_t^{t+\tau} \sigma^2_{i,s} ds \right]} \sqrt{E^Q_t \left[ \int_t^{t+\tau} \sigma^2_{j,s} ds \right]},$$

we can devise an alternative measure of dependence among the index constituents by computing

$$\theta^Q_{\text{Index},\tau}(t) = \frac{E^Q_t \left[ \int_t^{t+\tau} \sigma^2_{\text{Index},s} ds \right] - \sum_{i=1}^N w_i^2 E^Q_t \left[ \int_t^{t+\tau} \sigma^2_{i,s} ds \right]}{E^Q_t \left[ \int_t^{t+\tau} \sigma^2_{\text{Index},s} ds \right]},$$

and the corresponding analogues $\theta^\mathbb{P}_{\text{Index},\tau}(t)$ and $\theta_{\text{Index},\tau}(t)$. Unlike $\rho^Q_{\text{Index},\tau}(t)$, this measure makes no restrictive assumption on the correlation structure of the individual constituents of an index.
3 The diverging euro zone experience

Although the eleven original members of the European Monetary Union (EMU) were not formally confirmed until May 1998, financial markets had correctly anticipated their names long before (see e.g. Hardouvelis et al. (2006)). As a result, the large discrepancies in interest rates vis-à-vis Germany that had prevailed during the Exchange Rate Mechanism - a target zone system that still acts as lead-in to EMU - narrowed surprisingly fast, and their volatilities also shrank (see Sentana (2002) and the references therein). The euro, formally launched on January 1st, 1999, brought about a period of low interest rates that coincided with a reduction in inflation levels and an increase in growth rates across the world.

However, important imbalances began to build up very soon. The so-called peripheral countries, or GIIPS (Greece, Ireland, Italy, Portugal and Spain) accumulated important current account deficits, which were effectively financed by the core countries (Austria, Belgium, Finland, France, Germany, Luxembourg and the Netherlands). Unfortunately, those funds were not necessarily invested in increasing the productive capacity of the GIIPS, which in fact suffered a progressive deterioration of competitiveness due to their inflation differentials.

The financial crisis that began in the US with the failure of two Bear Stearns subprime hedge funds in June 2007 and reached its peak after the fall of Lehmann Brothers in September 2008, led to a very deep global recession, with a substantial cyclical effect on budget deficits, and eventually to a sudden stop in the funding of those external imbalances. The impossibility of effectively reducing the accumulated public debt burden by means of either higher inflation or devaluation, the lack of absorption mechanisms for asymmetric shocks within the EMU, and several policy mistakes on the part of the monetary and fiscal authorities, eventually led to the European sovereign crisis (see Baldwin et al (2015) for a lengthy but insightful narrative).

Nevertheless, the unfolding of this crisis was far from homogeneous. The first country whose public finances were subject to the scrutiny of financial markets was Greece. Two days after the newly formed Greek government announced in October 2009 that the public deficit was expected to reach 12.5% by the end of that year, Fitch downgraded its debt, with Standard and Poor’s (S&P) and Moody’s following suit soon afterwards. Despite the Greek parliament approving two consecutive austerity packages in February and March, 2010, the government formally requested an international bailout at the end of April, whose terms, including a third austerity package, were agreed with the European Union (EU), the European Central Bank
(ECB) and the International Monetary Fund (IMF) in early May.

But although these measures alleviated the funding problems of Greece, whose 10-year bond interest rate differentials with German bunds had reached 10%, they failed to contain the damage, and the crisis quickly spread to other countries. On April 27, 2010, S&P not only downgraded Greek debt to junk status, but also lowered by two notches its assessment of Portuguese bonds, explicitly suggesting that they could also lose their investment grade soon. The next day, it reduced the rating of Spanish bonds from AA to AA-. Still, financial markets took a more relaxed attitude after the first Greek bailout and the seeming presence of some “green shoots”, but they remained vigilant, with a few hick ups in the second half of 2010.

Unfortunately, the expected strong global recovery did not materialise, the Greek government failed to solve its funding problems, which were in fact larger than previously thought once some creative accounting practices were eliminated, and one downgrade followed another all along 2011. Confronted with increased opposition in parliament and especially the streets, at the end of October the Greek prime minister announced a referendum on the fresh austerity measures imposed on his country after an agreed private sector re-structuring of its public debt, which he called off a few days later under overwhelming pressure from other European governments, the ECB and IMF, leading to his resignation.

In the meantime, Ireland and Portugal had also been forced to apply for a rescue package from the EU and the IMF in November 2010 and May 2011, respectively, Spanish and Italian government bonds spreads increased substantially, and the ratings of both the sovereign debts of those two countries and many of their banks were reduced in what became known as a “diabolic loop”. In turn, Belgium had to nationalise the domestic arm of Dexia because of its exposure to Greek debt, which also led to a reduction in this country’s sovereign credit rating. By early January 2012, S&P had downgraded all euro area government ratings except Finland, Germany, Luxembourg and the Netherlands.

There have been many economic analyses of the euro area crisis using both macro economic time series, such as inflation, employment and output, and financial indicators, such as interest rate differentials and insurance premia implicit in credit default swaps of both sovereign debt and private debt issued by European financial institutions. Other studies have looked at the evolution of alternative financial variables, such as the stock prices and risk management measures of some of the largest banks in the euro zone (see e.g. Amengual, Fiorentini and Sentana (2013)). In the
rest of this section, though, we take a somewhat heterodox approach, and look at the implied
correlations obtained from the data described in section 2.

Figure 1 displays the historical evolution of the implied vol of the Euro Stoxx 50 we have
computed using the procedures described in that section, comparing it to the VSTOXX volatility
index reported by Stoxx itself. Reassuringly enough, the correlation between both series is close
to 99%. As other volatility measures, these series are characterised by swings from low to
high levels, with a temporal pattern that shows mean reversion over the long run but displays
strongly persistent deviations from the mean during extended periods. Interestingly, the period
that preceded the global financial crisis is a low volatility one, in what some have called “the
calm before the storm”. Over the following year, though, the VSTOXX index increased to values
between 20 and 40. Finally, in the autumn of 2008 it reached unprecedented levels. After this
peak, volatility followed a decreasing trend over the following months until the end of March,
2010, when the Greek debt crisis started worsening, jumping back again during the euro crisis
in 2012. Over the same period, the evolution of the VIX, the analogous volatility index for the
S&P500, is broadly similar (see e.g. Mencía and Sentana (2013)).

The similarity is even stronger for the implied vols associated to some of the national stock
market indices in Europe. Figures 2a, 2b and 2c compare the Euro Stoxx 50 implied vols for
horizons of 1 month, 3 months and 1 year, respectively, with the corresponding vols for the CAC
and the DAX between the beginning of 2007 until the present. Although the largest French and
German companies belong to both the Euro Stoxx 50 and their national indices, the correla-
tions among the three series is remarkable, and confirm once again the strong comovements in
international stock markets. As can be seen in Table 2, their average levels are also surprisingly
close, with the DAX slightly lower, which probably reflects they are all based on firms with
large capitalisations. Both these features are shared across the three horizons, although the
mean reverting nature of volatilities implies that the average levels decrease with the horizon
length.

Figures 3a-c carry out the analogous comparison for the Belgium (BEL) and Dutch (AEX)
national stock market indices, while Figures 4a-c do the same for the Spanish (IBEX) and Italian
(MIB) ones. While Belgium and Dutch implied vols, which are noticeably lower on average,
hardly offer any new insights on the global financial crisis or European sovereign debt one, the
evolution of the Spanish and Italian ones between 2010-2012 is far more interesting. Figures
5a-c, which zoom in over this period, clearly indicate that the events in Greece, Ireland and Portugal that we have previously mentioned, substantially affected the two largest economies in the European periphery.

The evidence discussed so far is suggestive of strong links between the different financial markets in Europe, but it does not directly measure their dependence. As is well known, the volatility of a stock market index is mainly driven by a combination of two factors: the individual volatilities of the index constituents and the correlations between their returns. On this basis, we present in Figure 6a a simple decomposition of the implied vol of the Euro Stoxx 50 index into two components: the implied vol that this index would have if all the pairwise correlations between its constituents were 0, which we denote by “constituents”, and the rest, denoted by “dispersion”, which is exclusively due to the off-diagonal elements of the conditional covariance matrix. As expected, both the volatility of the individual constituents and their dependence rises in crisis periods. However, the importance of the two components is surprisingly different. Most of the volatility of the Euro Stoxx index seems to be due to the dependence among its components, rather than the individual volatilities of its constituents. This result, coupled with the close similarity between the implied vols of the Euro Stoxx and the national indices that we discussed above, is indicative of a high degree of interdependence across the largest companies in the eurozone.

A more direct measure of dependence between European stocks is provided by the implied correlation of the Euro Stoxx index described in (2), which we plot in Figure 6b. As we mentioned before, this implied correlation of the index is a measure of the market’s expectation of the future correlation of the index components. The first noticeable feature is that the median correlation value is rather high (64%). In addition, the temporal pattern of this series confirms the stylised fact that correlations increase in periods of high volatility. The rank correlation between the Euro Stoxx implied vol and correlation series is 53.13%, but the spikes during the global financial crisis, and especially the run-ups to the first and second Greek bailouts are even more telling. Unlike what happened with the turmoil in the US in the autumn of 2008, whose effects on the Euro Stoxx implied correlation were short lived, the sovereign debt crisis led to a sustained increase. In fact, the median implied correlation value was almost 75% in the years 2010-2012, and the (rank) correlation of its movements with those of the Euro Stoxx implied vol measure

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6There is an alternative additive decomposition in terms of variances, as opposed to standard deviations, but the use of square units makes it more difficult to grasp visually.
at the 3 month horizon also increased to 79.95%.

Finally, we investigate the previously mentioned negative feedback loop between banks and weak sovereigns in several peripheral euro area countries by looking at the evolution of the implied vols of four Global Systemically Important Banks from the eurozone, comparing them to the implied vols of four public utilities companies. Specifically, we look at flagship commercial banks from France (BNP Paribas), Germany (Deutsche Bank), Italy (Intesa San Paolo) and Spain (Banco Santander), and equally prominent utility companies: Engie (France), E.On (Germany), Enel (Italy) and Iberdrola (Spain).

Figure 7a shows that although all four financial institutions were affected in varying degrees by the turmoil in financial markets after the Lehmann Brothers collapse, the effects of the European sovereign debt crisis was more heterogeneous. Somewhat surprisingly, Deutsche Bank and especially BNP Paribas were far more affected than Intesa and Santander in the second half of 2011, a period in which the details of the private debt re-structuring deal for Greece were being discussed. Unfortunately, there is no reliable high frequency data on those banks’ balance sheet structure. Nevertheless, many commentators attributed such differences to the extent these financial institutions were stricken with Greek sovereign debt. On the other hand, Intesa and especially Santander were much more affected in the spring of 2012, which is precisely when the Italian and Spanish governments’ borrowing costs rocketed.

Figure 7b, on the other hand, illustrates that the implied vols of the utility companies are rather different. Not surprisingly, banks have larger implied vols on average than utilities, which to some extent reflects the procyclical nature of their revenue base but also the leveraged nature of their capital structure. But the implied vols of the utilities were also far less sensitive to the euro zone sovereign debt crisis, with the exception of Iberdrola in the 2012, which experimented unusually high levels.

4 The Spanish experience

Spain had a modest ratio of public debt to GDP of 36% at the outset of the global financial crisis. In addition, as we have seen in the previous section, the initial effects of the sovereign debt crisis on this country were arguably triggered by events in Greece and elsewhere. As it is usually the case in episodes of financial contagion, though, Spain had some serious economic problems of its own. Its seemingly good fiscal position was largely due to the huge construction-related
tax revenues generated during the housing bubble, which allowed for large increases in local, regional and federal government spending in public consumption and infrastructure (not necessarily guided by economic efficiency criteria) to remain blurred in the aggregate figures. While subprime mortgages were not a major problem for banks thanks to their recoursing character and the safety net provided by families, competition for market share earlier on, implemented through generous revolving credit facilities to property developers, quickly increased the volume of “zombie” loans on the financial sector books. The socialist government first, and the conservative one that was elected at the end of 2011, implemented three tepid and arguably misguided financial reforms, but to no avail. On June 1st, 2012, just three weeks after nationalising Bankia, a bank resulting from the merger two years earlier of seven regional savings banks in difficulties, the Spanish 10-year bond reached 548 basis points above its German counterpart on intraday trading. The Spanish government rather reluctantly agreed a very large European financial rescue package for its banks, but in the second half of July the spread on German bunds reached 6%, and the irreversibility of EMU was in doubt. The famous “whatever it takes” speech by the president of the ECB backed by the German chancellor, and a far more aggressive reform of the Spanish financial system, including the creation of a bad bank, reduced those spreads by 140 basis points in only five days. By mid October, interest rate differentials were a mere 2.4%, and the Spanish Treasury was able to issue short term debt at less than 1%.

We can use the same methods that we used in the previous section to shed some light on the Spanish experience too. Figure 8a presents the decomposition of the implied vol of the IBEX35. In marked contrast to the Euro Stoxx 50 index, the importance of both components in the IBEX 35 is roughly similar, except in the last part of the sample, when a large fraction in the reduction of the implied vol of the index seems to be due to the reduction of the implied vols of its constituents. One possible explanation for this phenomenon is that the largest Spanish companies are internationally diversified, so that their revenue sources are more affected by sectoral factors than country risks. In turn, Figure 8b indicates that the implied correlation of the IBEX is roughly of the same magnitude as that of the Euro Stoxx (median=67%), although it seems to increase by less when volatility increases (rank correlation=.35).

Finally, in Figures 9a and b we compare the implied vols of the two largest Spanish banks (Santander and BBVA) with the implied vols of its two largest utility companies (Iberdrola and Gas Natural). As we saw in figures 7a and b, banks have larger implied vols on average than
utilities. In addition, the implied vols of these banks reacted more strongly to the European sovereign debt crisis than the implied vols of the utilities despite the fact that their own solvency was not at stake, which confirms the diabolic loop. Nevertheless, the dramatic increase of all four series in the spring of 2012 reflects the extent to which investors were concerned with the prospects of the Spanish economy before the government finally decided to appeal to the European institutions for help.

5 Conclusions

Increasing economic and financial integration implies that nowadays countries are more sensitive to shocks originating outside their frontiers. The global concerns raised by the US financial crisis of 2007-08 and the European sovereign debt crisis of 2010-12 are truly a sign of our times.

One common characteristic of both these crises, which they share with the emerging market crises that preceded them in the 1980s and 90s, is that they typically start in a single country but they rapidly spread to others, even though the direct economic and financial links between the original country and some of the affected ones are fairly weak.

In this paper, we analyse this phenomenon, commonly known as financial contagion, by focusing on its most recent example: the European sovereign debt crisis. Importantly, we do not need to worry about the effects of the crisis on exchange rates within the euro area because all along they remained fixed at the levels agreed vis a vis the euro at the end of 1998 just before EMU took off. But our main point of departure from the existing literature is that we not only look at the returns on primitive assets, such as stocks, but also consider financial derivatives. Specifically, we look at volatility measures extracted from option prices. Furthermore, we combine return and option data on the individual companies that constitute an index with the corresponding data for the index itself to provide measures of excess dispersion and implied correlation.

One of our main findings is the close similarity between the movements of the implied vols of the main national stock market indices and the Euro Stoxx, which clearly exceeds the correlations between the returns on those indices. Nevertheless, we also observe that the volatility of Italian and Spanish stock markets, the two largest periphery economies, tended to increase noticeably more during the spring of 2012. In addition, we find that the effects of the sovereign debt crisis
on European financial institutions and utilities was very different. Moreover, we also observe that French and German banks were affected early on due to their large holdings on Greek public debt, while Italian and Spanish banks suffered the most in 2012 through a negative feedback loop that linked the credit default premia on these banks to the country risk premia for their weak sovereigns.

The empirical analysis of financial contagion that we conduct is very relevant for the analysis and understanding of the workings of asset markets and their role in the global economy, especially in situations of financial distress. As a result, it could prove very useful both for professional investors who diversify their portfolio internationally, as well as for international financial institutions who supervise the financial stability of the global financial system.

In the case of investors, dispersion trading refers to trades in which one sells index options and buys options on the index components, or vice versa. The main motivation for building this type of strategies is to profit from price differences in volatility markets using index options and options on individual stocks due to market segmentation, idiosyncratic news on individual stocks or temporary shifts in correlations between assets. This last point justifies the need for an accurate description of the correlation structure across index constituents.

On the other hand, some of the empirical features that we illustrate, such as the positive correlation between volatility and correlation, can also inform the regulatory debate. In particular, the speed at which measures aimed at reducing the risks of banks and other financial institutions should be implemented when market volatility increases ought to take into account the possibility that herd behaviour might lead to fire sales.

These, and many other questions, constitute obvious avenues for further research.
References


Appendix

A Data Appendix

We use rely on daily data from the OptionMetrics Ivy DB Europe database for options on the EuroStoxx50, the BEL20, the CAC40, the DAX30, the FTSE MIB40, the AEX25 and the IBEX35, from January 2002 until November 2016.

Specifically, from the Compustat database we obtain:

- Entry and exit dates of companies ever appeared in each index. In this file, each company has a unique ISIN and some companies may have multiple entry and exit dates.
- Number of shares outstanding of companies ever appeared in each index. Each company has a unique ISIN. Note that some companies have multiple issues of stocks.

From the OptionMetrics Ivy DB Europe database we use:

- Security_Name file: To obtain the Security ID that identifies each index/firm within OptionMetrics using the ISIN number from Compustat.
- Option_Price and Option files: To obtain, for the relevant maturities, open interest and last price which are the measures we use as selection criteria for excluding illiquid firms from the calculations.
- Volatility_Surface file: To obtain implied volatilities from OTM European call and put options for the different time-to-maturity we consider, which constitute the basis for the computation of the expected risk-neutral integrated variance at different horizons.
- Security_Price and Zero_Curve files: To obtain series for the underlying and the interest rate, respectively, required for the computation of the synthetic European calls and puts that appear in equation (1).
- Historical_Volatility file: To obtain series for the realized volatility for the different horizons, required for the implied dispersion and correlation under the objective measure $P$.

Additionally, for the IBEX35 we obtain historical daily series of actual weights and changes in the index composition from Bolsas y Mercados Españoles. To exploit this source we use Ticker file to find the corresponding identifier for the IBEX components.

The number of different companies ever appeared in all indices (excluding those with missing Security ID) is 297. And the number of different companies without Security ID is 30. The list of companies without Security ID for each index is shown in Table A1.
### Table A1: Firms excluded from the analysis

<table>
<thead>
<tr>
<th>Index</th>
<th>Company name</th>
<th>Compustat ISIN</th>
<th>EuroStoxx50</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEL20</td>
<td>ALMANIJ NV</td>
<td>BE0003703171</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BARCONET NV</td>
<td>BE0003791085</td>
<td></td>
</tr>
<tr>
<td></td>
<td>COBEP A</td>
<td>BE0003673846</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GIB GROUP (GB-INNO-BM)</td>
<td>BE0003576841</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GROUP BRUXELLES LAMBERT -OLD</td>
<td>BE0003494029</td>
<td></td>
</tr>
<tr>
<td>CAC40</td>
<td>ARCELORMITTAL</td>
<td>LU1598757687</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>AVENTIS SA</td>
<td>FR0000130460</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>CREDIT LYONNAIS SA</td>
<td>FR0000140071</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EQUANT NV</td>
<td>NL0000200889</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HSBC FRANCE</td>
<td>FR0000047367</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LEGRAND SA</td>
<td>FR0000120610</td>
<td></td>
</tr>
<tr>
<td>DAX30</td>
<td>DRESDNER BANK AG</td>
<td>DE0005350003</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>VIAG AG</td>
<td>DE0007626202</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VODAFONE AG</td>
<td>DE0006560303</td>
<td></td>
</tr>
<tr>
<td>FTSE MIB40</td>
<td>BANCA ANTONVENETA POPOLARE</td>
<td>IT0003270102</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BANCA COMMERCIALE ITALIANA</td>
<td>IT0000066198</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BANCA POPOLARE DI BERGAMO</td>
<td>IT0000064409</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BNL-BANCA NAZIONALE LAVORO</td>
<td>IT0001254892</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EDISON SPA - OLD</td>
<td>IT0000072832</td>
<td></td>
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<tr>
<td></td>
<td>ITALGAS GROUP</td>
<td>IT0003049217</td>
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<tr>
<td></td>
<td>MONTEDISON SPA - OLD</td>
<td>IT000138620</td>
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<td></td>
<td>PARMALAT FINANZIARIA SPA</td>
<td>IT0003121644</td>
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<td></td>
<td>PIRELLI SPA</td>
<td>IT0000088481</td>
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<td></td>
<td>ROLO BANCA 1473 SPA</td>
<td>IT0001070405</td>
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<td></td>
<td>SAIPEM SPA</td>
<td>IT0005252140</td>
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<tr>
<td></td>
<td>TECNOST SPA</td>
<td>IT0000088820</td>
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<tr>
<td>AEX25</td>
<td>ARCELORMITTAL</td>
<td>LU1598757687</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>CMG PLC</td>
<td>GB0003847372</td>
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<td></td>
<td>GUCCI GROUP NV</td>
<td>NL0000359552</td>
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<td></td>
<td>KONINKLIJKE VENDEX KBB</td>
<td>NL0000390979</td>
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<td></td>
<td>ROYAL DUTCH PETROLEUM NV</td>
<td>NL0000009470</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>UNITED PAN-EUROPE COMMNS NV</td>
<td>NL0000389112</td>
<td></td>
</tr>
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</table>

Notes: This table reports the constituents missing from our empirical computations due to mismatch bewteen the ISINs from the Compustat database and the OptionMetrics Ivy DB Europe database. We are able to identify all the constituents of IBEX35 using the OptionMetrics’s Ticker file to find the corresponding identifier for the IBEX components.
Table 1: Indices constituents, review dates, and option data availability

<table>
<thead>
<tr>
<th>Index</th>
<th>Country or region</th>
<th>Option data since</th>
<th>Review of free float factors and number of shares</th>
<th>Review of composition</th>
<th>Total number of constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>EuroStoxx50</td>
<td>Eurozone</td>
<td>Jan 2, 2002</td>
<td>Reviewed on quarterly basis.</td>
<td>Quarterly review effective on third Friday of Mar, Jun, Sep and Dec.</td>
<td>78 71</td>
</tr>
<tr>
<td>BEL20</td>
<td>Belgium</td>
<td>Jan 2, 2002</td>
<td>Annual in March, quarterly update if ff (# shares) changes more than 10% (20%).</td>
<td>Quarterly review effective on third Friday of Mar, Jun, Sep and Dec.</td>
<td>41 29</td>
</tr>
<tr>
<td>CAC40</td>
<td>France</td>
<td>Apr 14, 2003</td>
<td>Annual in Sep, quarterly update if ff (# shares) changes more than 10% (20%).</td>
<td>Quarterly review effective on third Friday of Mar, Jun, Sep and Dec.</td>
<td>64 57</td>
</tr>
<tr>
<td>DAX30</td>
<td>Germany</td>
<td>Jan 2, 2002</td>
<td>Number of shares and ff factors are updated quarterly.</td>
<td>Quarterly review on third trading day of Mar, Jun, Sep and Dec.</td>
<td>49 46</td>
</tr>
<tr>
<td>FTSE MIB40</td>
<td>Italy</td>
<td>Oct 10, 2006</td>
<td>Quarterly update to ff applied after closing third Friday of Mar, Jun, Sep and Dec.</td>
<td>Quarterly review after closing third Friday of in Mar, Jun, Sep and Dec.</td>
<td>63 39</td>
</tr>
<tr>
<td>AEX25</td>
<td>Netherlands</td>
<td>Jul 1, 2005</td>
<td>Annual in March, quarterly update if ff (# shares) changes more than 10% (20%).</td>
<td>Quarterly review effective on third Friday of Mar, Jun, Sep and Dec.</td>
<td>63 51</td>
</tr>
<tr>
<td>IBEX35</td>
<td>Spain</td>
<td>Oct 11, 2006</td>
<td>At ordinary reviews of the Technical Advisory Committee, and at follow up meetings.</td>
<td>At ordinary, follow up, and extraordinary meetings of Technical Advisory Committee</td>
<td>73 47</td>
</tr>
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</table>

Table 2: Summary statistics of volatilities from variance swap rates

<table>
<thead>
<tr>
<th>Index</th>
<th>Time to maturity</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>Constituents</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>EuroStoxx50</td>
<td>1 month</td>
<td>27.1</td>
<td>13.5</td>
<td>103.6</td>
<td>34.8</td>
<td>0.0</td>
<td>284.3</td>
<td></td>
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<tr>
<td></td>
<td>3 months</td>
<td>25.3</td>
<td>13.8</td>
<td>70.6</td>
<td>32.2</td>
<td>1.9</td>
<td>227.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>24.3</td>
<td>14.4</td>
<td>50.4</td>
<td>30.4</td>
<td>4.2</td>
<td>147.0</td>
<td></td>
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<tr>
<td>BEL20</td>
<td>1 month</td>
<td>23.9</td>
<td>13.2</td>
<td>83.5</td>
<td>44.2</td>
<td>7.6</td>
<td>301.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 months</td>
<td>22.0</td>
<td>12.2</td>
<td>65.3</td>
<td>39.7</td>
<td>13.1</td>
<td>268.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>21.7</td>
<td>13.2</td>
<td>48.1</td>
<td>30.3</td>
<td>7.4</td>
<td>147.0</td>
<td></td>
</tr>
<tr>
<td>CAC40</td>
<td>1 month</td>
<td>26.5</td>
<td>13.7</td>
<td>82.3</td>
<td>35.5</td>
<td>7.8</td>
<td>301.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 months</td>
<td>24.9</td>
<td>14.6</td>
<td>70.4</td>
<td>33.2</td>
<td>7.8</td>
<td>268.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>24.4</td>
<td>16.3</td>
<td>49.2</td>
<td>31.6</td>
<td>9.1</td>
<td>139.9</td>
<td></td>
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<tr>
<td>DAX30</td>
<td>1 month</td>
<td>26.2</td>
<td>15.1</td>
<td>85.4</td>
<td>35.5</td>
<td>0.0</td>
<td>274.6</td>
<td></td>
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<tr>
<td></td>
<td>3 months</td>
<td>24.2</td>
<td>14.5</td>
<td>67.9</td>
<td>33.2</td>
<td>1.9</td>
<td>251.8</td>
<td></td>
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<tr>
<td></td>
<td>1 year</td>
<td>23.7</td>
<td>16.6</td>
<td>52.0</td>
<td>31.7</td>
<td>4.2</td>
<td>180.4</td>
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<tr>
<td>FTSE MIB40</td>
<td>1 month</td>
<td>29.4</td>
<td>5.9</td>
<td>73.6</td>
<td>35.8</td>
<td>8.9</td>
<td>159.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 months</td>
<td>27.7</td>
<td>13.4</td>
<td>62.6</td>
<td>34.0</td>
<td>11.7</td>
<td>169.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>26.7</td>
<td>15.1</td>
<td>46.1</td>
<td>33.4</td>
<td>10.9</td>
<td>128.3</td>
<td></td>
</tr>
<tr>
<td>AEX25</td>
<td>1 month</td>
<td>24.6</td>
<td>6.1</td>
<td>86.4</td>
<td>36.5</td>
<td>3.1</td>
<td>301.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 months</td>
<td>22.8</td>
<td>5.6</td>
<td>76.2</td>
<td>33.8</td>
<td>6.3</td>
<td>267.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>22.1</td>
<td>5.5</td>
<td>54.2</td>
<td>31.9</td>
<td>3.5</td>
<td>149.6</td>
<td></td>
</tr>
<tr>
<td>IBEX35</td>
<td>1 month</td>
<td>30.4</td>
<td>18.5</td>
<td>83.7</td>
<td>37.7</td>
<td>2.2</td>
<td>196.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 months</td>
<td>28.4</td>
<td>17.7</td>
<td>69.2</td>
<td>34.7</td>
<td>11.0</td>
<td>185.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>27.0</td>
<td>17.7</td>
<td>44.9</td>
<td>32.9</td>
<td>14.2</td>
<td>126.7</td>
<td></td>
</tr>
</tbody>
</table>

Notes: In this table we report mean, minimum and maximum of the square root of the annualized variance swap rates in percentage points for the EuroStoxx50 (SX5E, largest companies in the Euro zone), the BEL20 (Belgium), the CAC40 (France), the DAX30 (Germany), the FTSE MIB40 (Italy), the AEX25 (the Netherlands) and the IBEX35 (Spain). The sampling period is from July 1st, 2006 to November 30th, 2016. Variance swap rates for each index and maturity are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003).
Figure 1: Volatilities from one-month time-to-maturity variance swap rates for EuroStoxx50 and V2TX

Notes: In this figure we plot the square root of the annualized one-month time-to-maturity variance swap rates for the EuroStoxx50 (SX5E, largest companies in the Euro zone) and the EURO STOXX 50® Volatility index(V2TX). The sampling period is from January 2nd, 2002 to November 30th, 2016. Variance swap rates for are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.
Notes: In this figure we plot the square root of the annualized variance swap rates for the EuroStoxx50 (SX5E, largest companies in the Euro zone), the CAC40 (France) and the DAX30 (Germany). The sampling period is from July 1st, 2006 to November 30th, 2016. Variance swap rates for each index and maturity are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.
Figure 3: Volatilities from variance swap rates for EuroStoxx50, AEX25 and BEL20

Notes: In this figure we plot the square root of the annualized variance swap rates for the EuroStoxx50 (SX5E, largest companies in the Euro zone), the BEL20 (Belgium), and the AEX25 (the Netherlands). The sampling period is from July 1\textsuperscript{st}, 2006 to November 30\textsuperscript{th}, 2016. Variance swap rates for each index and maturity are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.
Figure 4: Volatilities from variance swap rates for EuroStoxx50, IBEX35 and FTSE MIB40

Notes: In this figure we plot the square root of the annualized variance swap rates for the EuroStoxx50 (SX5E, largest companies in the Euro zone), the FTSE MIB40 (Italy) and the IBEX35 (Spain). The sampling period is from July 1st, 2006 to November 30th, 2016. Variance swap rates for each index and maturity are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.
Figure 5: Volatilities from 3 months time-to-maturity variance swap rates during the European sovereign debt crisis

Notes: In this figure we plot the square root of the annualized variance swap rates for the EuroStoxx50 (SX5E, largest companies in the Euro zone), the BEL20 (Belgium), the CAC40 (France), the DAX30 (Germany), the FTSE MIB40 (Italy), the AEX25 (the Netherlands) and the IBEX35 (Spain). The sampling period is from January 2nd, 2010 to December 31st, 2012. Variance swap rates for each index are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi et al (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.
Notes: In this figure we plot the implied vol decomposition of the annualized three-months time-to-maturity variance swap rates for the EuroStoxx50 (SX5E, largest companies in the Euro zone), as well as its implied correlation. The sampling period is from January 2\textsuperscript{nd}, 2002 to November 30\textsuperscript{th}, 2016. Variance swap rates for each index/stock are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.
Figure 7: Volatilities from three-months time-to-maturity variance swap rates during the European sovereign debt crisis

Figure 7a: EuroStoxx50 and main Euro banks

Notes: In this figure we plot the square root of the annualized variance swap rates for the EuroStoxx50 (SX5E, largest companies in the Euro zone), BNP Paribas (BNP), Deutsche Bank (DBK), Banca Intesa Sanpaolo (ISP), Banco Santander (SAN), Ente Nazionale per l’Energia eLettrica (ENEL), Engie/GDF Suez (ENGI) and Iberdrola (IBE). The sampling period is from June 1st, 2007 to November 30th, 2016. Variance swap rates for each index are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.
Notes: In this figure we plot the implied vol decomposition of the annualized three-months time-to-maturity variance swap rates for the IBEX 35 (Spain), as well as its implied correlation. The sampling period is from May 14th, 2007 to November 30th, 2016. Variance swap rates for each index/stock are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.
Figure 9: Volatilities from three-month time-to-maturity variance swap rates during the European sovereign debt crisis

Figure 9a: IBEX35 and main Spanish banks

Figure 9b: IBEX35 and main utilities companies

Notes: In this figure we plot the square root of the annualized variance swap rates for the IBEX35 (largest companies in Spain), Banco Santander (SAN), Banco Bilbao Vizcaya Argentaria (BBVA), La Caixa/CaixaBank (CABK), Iberdrola (IBE), Gas Natural SDG (GAS) and Endesa (ELE). The sampling period is from June 1st, 2007 to November 30th, 2016. Variance swap rates for each index are computed using observations across all strikes of out-the-money (OTM) options from the OptionMetrics Ivy DB Europe database, following the methodology proposed by Bakshi, Kapadia and Madan (2003). Vertical lines correspond to 15-Sep-2008, 23-Apr-2010, 29-Nov-2010, 21-Jul-2011, 26-Oct-2011 and 1-Jun-2012.