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# Scenario for the European Securities and Markets Authority's EU-wide central counterparty stress test in 2016

## Introduction

In accordance with its mandate, the European Securities and Markets Authority (ESMA), in cooperation with the ESRB, initiates and coordinates EU-wide stress tests to assess the resilience of financial institutions to adverse market developments. It plans to conduct a stress test this year for central counterparties (CCPs). On ESMA's request, the ESRB has developed adverse macro-financial scenarios for this stress test, which are set out in this document.

## The scenario approach

CCPs were set up to reduce systemic risk that stems from bilateral counterparty connections owing to the fact that trading activity carried out both over the counter and on trading venues forms a network in which idiosyncratic shocks can result in a cascade of defaults among interconnected counterparties.

The very nature of CCPs can require an ad-hoc approach to stress-testing and scenario design, in contrast to the approaches typically applied to scenarios defined for bank or insurance stress tests. As a CCP is a counterparty to all its clearing members, it is super-systemic and its default could endanger the entire financial system. For this reason, CCPs are designed to be very resilient. The approach taken to developing a scenario for the CCP stress test needs to take into account the specificity of the CCP business model and the regulatory requirements imposed on CCPs.

Regulatory requirements imposed on CCPs make it challenging to design a macro-financial scenario that is both internally consistent and relevant from the perspective of the regulator, for two reasons. First, the European Market Infrastructure Regulation, or EMIR, requires CCPs to be able to survive losses stemming from the simultaneous default of their two largest clearing members (the "cover 2" principle). With 17 EU CCPs undergoing the ESMA stress testing exercise, this could in theory require a default assumption covering up to 34 clearing members. However, as a given financial group operating in the EU can be among the two largest clearing members for more than one CCP, aggregating over the 17 CCPs results in a smaller number than 34. That said, even this number of simultaneous defaults would be without precedent, and an internally consistent macro-financial scenario combining these defaults with market developments would be implausible. This is because it would imply unrealistic paths for macro-financial variables, in particular over the short horizon over which CCPs maintain open counterparty credit risk positions. Second, regulations also require that CCPs are resilient to extreme shifts in market prices. One of the Regulatory Technical Standards (RTS) outlining the framework of EMIR requires that CCPs have sufficient margin collateral to cover price risk up to the Value at Risk (VaR) at

the 99.5% confidence level for all over-the-counter (OTC) instruments,[1] while plausible stress above 99.5% must be covered by the mutualised guarantee fund. An internally consistent market risk scenario that exceeded these requirements would be implausible, as the probability of such extreme price shifts for all risk factors at the same time is almost zero, in particular at the very short horizon over which CCPs maintain open counterparty credit risk positions.

Even if the default assumptions and macro-financial scenarios are considered separately, an internally consistent macro-financial scenario might fall short of delivering sufficient financial market stress to challenge the solvency of a CCP. The reason is that – when CCPs are stressed using a single internally consistent macro-financial scenario – historical correlations between asset classes might result in some CCPs, which specialise in clearing certain assets, experiencing insufficient stress.

Recognising these challenges, this document provides independent input for the two building blocks of the CCP stress test: (1) default assumptions and (2) macro-financial scenarios (see Appendix, Sections 1.1 and 2.1 respectively). In addition, the methodology put forward in this note also takes account of the challenges related to the regulatory requirements imposed on CCPs. In particular, it proposes using reverse stress tests and ranking clearing members by probability of default (PD) for the default scenario. Moreover, the shock sizes are derived for each risk factor individually, disregarding the historical tail correlations between asset classes.

As regards the default assumptions, the scenario goes beyond the cover 2 principle applied to individual clearing members. It considers instead the default of the two largest EU financial groups (both on a consolidated basis in terms of exposure and in terms of exposure weighted by the PD). Stress tests should also assess the resilience of CCPs going beyond two defaults by means of reverse stress tests, whereby the number of clearing member defaults increases until the CCP guarantee fund is exhausted.

Regarding the macro-financial scenarios, first, an internally consistent adverse macro-financial scenario is put forward, derived from nonparametric simulations carried out for the purpose of calibrating the European Banking Authority (EBA) bank stress test scenario but adjusted to the shorter horizon of the CCP stress tests, i.e. two days (see Appendix, Sections 1.2.1 and 2.2.1). In addition, the note puts forward a “bespoke” macro-financial scenario which is not internally consistent, in the sense that it disregards historical tail correlation between asset classes, but is deemed better suited to the very specific nature of the CCP business model (see Appendix, Sections 1.2.2 and 2.2.2). Neither of these scenarios is deemed to provide the complete set of risk factors for all CCPs; they both focus on the major risk factors.

[1] For instruments other than OTC derivatives the margin collateral needs to cover price risk up to the VaR at the 99% confidence level.

# Appendix: Methodology and scenarios for the EU-wide CCP stress test

## 1. Methodology

### *1.1 Clearing member default scenarios*

Clearing member default scenarios should consider assumptions going beyond the EMIR cover 2 requirement. On top of the cover 2 principle applied on a solo basis to clearing members in terms of exposure, EU-wide stress tests of CCPs should also consider other default scenario assumptions. In particular, additional default scenarios could be applied, on a consolidated basis, to the top two EU financial groups in terms of exposure or in terms of exposure weighted by PD.

In addition, reverse stress tests could be applied to test CCPs' resilience beyond the cover 2 requirement. In such tests the number of clearing member defaults could be increased beyond two until the CCP's guarantee fund was exhausted.

Risk-based rankings of clearing members can be used as an input to the reverse stress tests. Default rankings in reverse stress tests are typically based on CCP members' combined exposure (combined for each member vis-à-vis all CCPs). This note proposes to include a PD element in the ranking, to capture not only the size of exposures but also the risk of CCP members defaulting. By way of example, consider two CCP members with equal CCP exposures but one facing a materially higher risk of default than the other. The two CCP members would obtain equal ranks if this was based on their exposure only, whereas if PDs are taken into consideration the riskier one would rank higher.

Two approaches to quantifying the PDs for all clearing members were employed. First, credit default swaps (CDSs) were used to infer annual PDs (five-year CDSs were used as they are the most liquid). Second, actual PDs from Merton-type models were used. Both approaches have advantages and disadvantages.

While CDS-implied PDs are available for a large number of institutions, they are not a reliable measure of actual PD. CDS-implied PDs have the following advantages: i) they can easily be computed from observed CDS spreads, without any further data (such as balance sheet information) being required; ii) they can be obtained for a comprehensive list of institutions, as CDSs are often traded for institutions without traded equity (the latter being a prerequisite for computing Merton-type model PDs). The disadvantages/caveats are: i) that CDS spreads, and hence the implied PDs, include a premium that reflects investor risk aversion and which leads to an upward bias relative to actual PDs; ii) they can be contaminated by implicit or explicit government guarantees, which is a concern in particular for large institutions, whose CDS-implied PDs would for that reason be expected to be downward-biased.

PDs inferred from Merton-type models are a more reliable measure of actual PDs. Their advantages mirror the CDS-implied PDs' disadvantages, i.e. they should not be contaminated by guarantees or risk premia. Their main disadvantage is that they are

available for a smaller number of institutions as their computation requires reliable balance sheet and equity price data.

## *1.2 Risk factor price shocks*

### 1.2.1 Internally consistent macro-financial scenario

The internally consistent adverse macro-financial scenario is derived from nonparametric simulations carried out for the purpose of calibrating the scenario for the EBA banking sector stress test.[2] Five trigger events are assumed to materialise in that scenario over a one-quarter horizon:

1) increase in US long-term Treasury bond yields;
2) fall in global equity prices;
3) increase in euro area weighted average sovereign credit spreads;
4) depreciation of a basket of central and eastern European currencies;
5) negative returns on investment in European shadow banking entities.

The severity of most of these trigger events, measured in isolation from the other events, is close to a 5% Expected Shortfall (ES) measure.

This scenario makes no explicit assumption regarding defaults of individual clearing members of participating CCPs, and any such assumptions made in the ESMA exercise are without prejudice to the results of the EBA exercise.

### 1.2.2 Financial shocks in the bespoke CCP stress test scenario

There is a twofold objective with respect to risk factor distributions and the derivation of shock sizes: 1) derivation of shock sizes corresponding to certain quantiles, designed to serve as benchmarks for the size of shocks reported by CCPs, on the basis of both parametric and nonparametric distributional assumptions; and 2) provision of "multiples" that reflect a move from the 99% to the 99.9% quantile for all risk factors, conditional on different distributional assumptions. These multiples can be used to scale, if desired for the sake of additional conservatism, the shock sizes reported by CCPs which correspond to a 99th percentile up to a 99.9th percentile.

The distributions that were employed include a parametric Gaussian and t-distribution, and a nonparametric distribution. The Gaussian distribution has the shortcoming of lacking the fat tails that distributions of high frequency financial market data normally exhibit. The t-distribution allows for fatter tails and is introduced for this reason. Moreover, the

[2] Owing to the much shorter horizon in which the stress is assumed to materialise in the ESMA exercise compared with the EBA exercise, the results of the simulations were adjusted using the square root of time approximation. The coverage of risk factors was also adjusted to match that of the ESMA exercise. For these reasons, the scenario presented in this note differs from the scenario published by the EBA.

nonparametric approach is fully agnostic to the shape of the distribution, i.e. there is no risk of misspecifying the shape of the distribution.[3,4]

The risk factors included in the analysis comprise 98 variables, which can be grouped into six broad categories: interest rates, bonds, equities, foreign exchange (FX), commodities, and CDSs. Interest rates and bonds cover, respectively, swap rates up to one year for the euro, US dollar, pound sterling and Swiss franc, and sovereign bond yields for G7 countries plus Switzerland and Canada. Equities covers European indices and sectoral sub-indices as well as a volatility index and dividend yields. Foreign exchange covers the exchange rates of the euro against the US dollar, the pound sterling and the Swiss franc. Moreover, the exchange rates of the euro vis-à-vis the Russian rouble and the Brazilian real are included to cover emerging markets. Commodities covers a wide range of asset prices from freight rates to grains, to oil and gas. Finally, the CDS category contains single names and indices for non-financial and financial corporates as well as sovereign CDSs.

## 2. Scenario for the EU-wide CCP stress test in 2016

### *2.1 Clearing member default scenarios*

The ranking of clearing members is based on CDS-implied and actual PDs. The CDS-implied PDs are based on data for five-year CDS spreads (see the Annex for more details on the computation). Table 1 provides an overview of the availability as well as the average of CDS-implied and actual PDs contained in the sample for the first 50 entries ("TOP50") as well as for the full sample of clearing members. In general, the availability of the data falls as the size of the exposures decreases. The coverage decreases from 96% for the TOP50 to about 51% for the full sample. A possible explanation is the availability of CDS and Moody's KMV data only for larger institutions. In addition, exposures correlate positively with the clearing/group member's total assets. The level of CDS-implied PDs is on average significantly higher than the actual PDs. Notably, the levels of both types of PD does not differ much between the subsample and the full sample.

[3] Yet the disadvantage of the nonparametric approach can be seen with respect to the notion of efficiency, which is to say that if a certain parametric distribution is known to be adequate, i.e. to reflect the "true" distribution, then it is more precise/efficient, in particular in the tails.

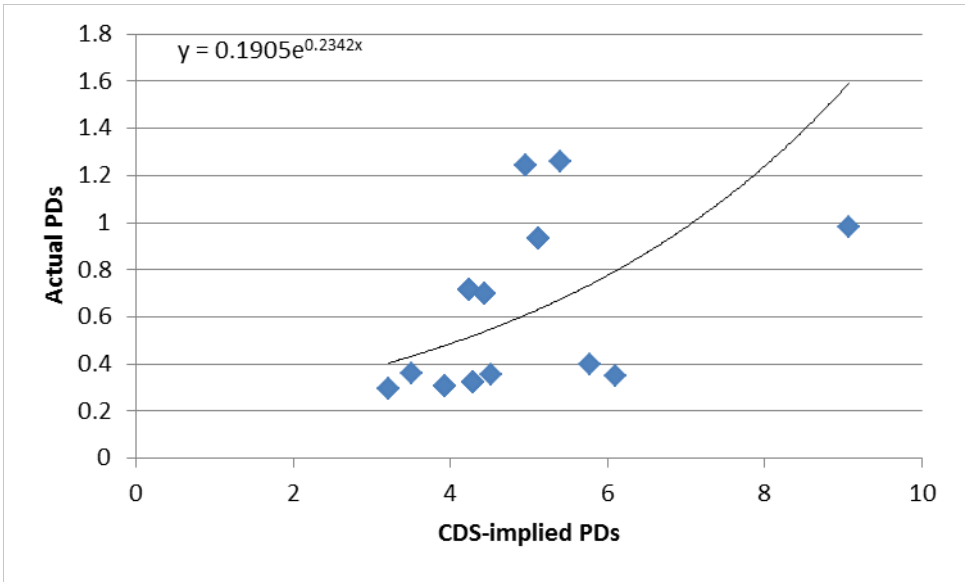
[4] A "smooth" bootstrap procedure for operationalising the nonparametric simulation approach was employed. It involves, in a first step, the estimation of a nonparametric kernel (Epanechnikov), to then, in a second step, generate a large number of bootstrap replicates by means of an accept-reject algorithm. On the basis of the bootstrap replicates, VaR and ES are then computed for pre-defined percentiles. This smooth bootstrap is an alternative to a "plain" bootstrap, which would not involve the kernel and accept-reject algorithm but consist of only plain resampling from historical data. The reason for applying the smooth bootstrap is that it helps avoid the replication of fine, spurious details in the data, which might be a concern in particular in relatively short samples.

Table 1: Coverage and summary statistics

| Coverage | | Median | | | |
|---|---|---|---|---|---|
| | | PD – CDS-implied | | PD – actual | |
| Top 50 | Full Sample | Top 50 | Full Sample | Top 50 | Full Sample |
| 96% | 51% | 4.47 | 4.43 | 0.72 | 0.71 |

Figure 1 shows a comparison of the CDS-implied and actual PDs for all clearing members for which both data points are available. Given that all data points are below the 45 degree line, Figure 1 confirms that not only is the average level of CDS-implied PDs significantly higher than that of the actual PDs but that this is also the case at the level of individual clearing members.

Figure 1: Scatter diagram of actual PDs against CDS-implied PDs (80% loss given default assumption)




While the CDS-implied PDs may exaggerate the risk of a default of a clearing member, this is not problematic as the focus is not on the level of the CDS-implied PDs but rather the ranking they imply.

## *2.2 Risk factor price shocks*

### 2.2.1 Internally consistent macro-financial scenario

Table A in the Annex presents the shocks obtained under the narrative of the internally consistent macro-financial scenario. In general, the resulting shocks are smaller than the range of movements in market variables estimated in Table B. This confirms that a scenario which is internally fully consistent and corresponds to a particular narrative would not deliver sufficient stress for all CCPs. This is particularly acute for a range of commodity

products, which have shown a weak relationship with the markets set to originate shocks in this scenario, such as equity and bond markets.

### 2.2.2 Financial shocks in the bespoke CCP stress test

Table B in the Annex summarises the shock sizes across all distributional assumptions considered. The results are reported for two different quantiles, namely for the 99% quantile and the 99.9% quantile, and distinguish between VaR and ES estimates. In addition, Tables A and B include the multiples which are computed as the ratio of the shock sizes at the 99.9% quantile and the 99% quantile. Table C separately reports the estimated degree of freedom parameters from the t-distributions for all factors. For all the simulations, the forward horizon was set to two business days.

The assumption of a Gaussian distribution would significantly underestimate the tail risk. The fact that the Gaussian estimates of shock sizes for individual risk factors and across quantiles in Table B are systematically lower than the shock sizes estimated under the fat-tailed parametric and nonparametric approaches confirms that the Gaussian assumption significantly underestimates the tail risk. The estimates of the degrees of freedom across risk factors in Table C further support this finding.

## ANNEX

### Computation of CDS-implied PDs

The following formula was used to compute CDS-implied PDs data from five-year CDS spreads

$$CDS-implied\ PD \cong \frac{\left(1-e^{-\left(\frac{CDS*T}{10000}\right)}\right)}{LGD}$$

where T denotes the maturity of the CDS and LGD denotes the loss given default of the clearing members. Since five-year CDS spreads were used, T is set equal to 5. Moreover, to avoid distorting the ranking implied by the CDS spreads, a uniform LGD of 80% was assumed. Actual PDs are based on the Moody's KMV Expected Default Frequency (EDF) credit measure. For the risk-based ranking based on CDS-implied PDs and actual PDs, the following pecking order was applied. If available, CDS-implied PDs and Moody's KMV EDFs at the level of the clearing member were computed. If a clearing member had no traded CDSs and/or no data were available in the Moody's KMV database, the same information at the level of the group to which the clearing member belongs was searched for. There are cases, and they become more numerous further down the table (sorted by exposure at default (EAD)), where CDS spreads are available at the clearing member level, while Moody's KMV EDFs are based on the parent company.

# Table A: Internally consistent macro-financial scenario

| asset class | risk factor | | shock size |
|---|---|---|---|
| Interest | Interest 1M | EUR | 2.7 |
| | Interest 1M | USD | 5.4 |
| | Interest 1M | GBP | 4.1 |
| | Interest 1M | CHF | 4.4 |
| | Interest 3M | EUR | 2.7 |
| | Interest 3M | USD | 5.9 |
| | Interest 3M | GBP | 4.4 |
| | Interest 3M | CHF | 2.9 |
| | Interest 1Y | DE | 7.7 |
| | Interest 1Y | US | 10.6 |
| | Interest 1Y | UK | 5.5 |
| | Interest 1Y | CH | 3.3 |
| | Interest 5Y | DE | 11.3 |
| | Interest 5Y | US | 25.6 |
| | Interest 5Y | UK | 13.8 |
| | Interest 5Y | CH | 6.6 |
| | Interest 10Y | DE | 11.1 |
| | Interest 10Y | US | 28.3 |
| | Interest 10Y | UK | 13.6 |
| | Interest 10Y | CH | 7.7 |
| Bond | Long | CA | 24.3 |
| | Long | CH | 10.0 |
| | Long | DE | 14.7 |
| | Long | FR | 16.9 |
| | Long | IT | 26.8 |
| | Long | JP | 1.3 |
| | Long | UK | 14.3 |
| | Long | US | 42.0 |
| | Medium | CA | 25.3 |
| | Medium | CH | 3.8 |
| | Medium | DE | 13.9 |
| | Medium | FR | 15.8 |
| | Medium | IT | 24.5 |
| | Medium | JP | 2.3 |
| | Medium | UK | 13.1 |
| | Medium | US | 37.5 |
| | Short | CA | 10.7 |
| | Short | CH | 5.5 |
| | Short | DE | 4.1 |
| | Short | FR | 4.3 |
| | Short | IT | 9.9 |
| | Short | JP | 0.9 |
| | Short | UK | 4.7 |
| | Short | US | 7.7 |

| asset class | | risk factor | shock size |
|---|---|---|---|
| Commodity | Certificate | EEX EU Emission Allowance | -0.8 |
| | Coal | Rotterdam | -1.8 |
| | Agri | Wheat | 0.0 |
| | Agri | Corn | -0.2 |
| | Freight | Europe-Asia | -0.1 |
| | Metal | Aluminium | -2.7 |
| | Natural Gas | TTF NL | -1.4 |
| | Natural Gas | NG1 | -1.4 |
| | Natural Gas | Henry Hub | -1.4 |
| | Gas Liquid | Ethane | -1.1 |
| | Oil | WTI | -5.1 |
| | Oil | Brent | -5.5 |
| | Power | Phelix | -3.9 |
| | Soft Com | Coffee | -2.4 |
| Equity | Consumer | Stoxx 600 Europe | -5.3 |
| | Energy | Stoxx 600 Europe | -6.0 |
| | Health | Stoxx 600 Europe | -3.9 |
| | Financial | Stoxx 600 Europe | -9.4 |
| | Comm | Stoxx 600 Europe | -4.8 |
| | Tech | Stoxx 600 Europe | -6.2 |
| | Utility | Stoxx 600 Europe | -5.6 |
| | Material | Stoxx 600 Europe | -7.8 |
| | Industrial | Stoxx 600 Europe | -7.0 |
| | Index | DAX30 | -6.3 |
| | Index | CAC40 | -6.9 |
| | Index | FTSE100 | -6.2 |
| | Vola | VSTOXX 1M | 6.2 |
| | Dividend | DAX30 | -7.0 |
| | Dividend | CAC40 | -7.0 |
| | Dividend | FTSE100 | -7.0 |
| FX | FX | USD | -0.7 |
| | FX | GBP | -0.7 |
| | FX | CHF | 0.8 |
| | FX | RUB | 7.7 |
| | FX | BRL | 1.9 |
| CDS | CDS | Single Name - Consumer | 19.7 |
| | CDS | Single Name - Energy | 11.0 |
| | CDS | Single Name - Health | 10.5 |
| | CDS | Single Name - Financial | 22.2 |
| | CDS | Single Name - Comm | 22.1 |
| | CDS | Single Name - Tech | 6.6 |
| | CDS | Single Name - Utility | 11.9 |
| | CDS | Single Name - Material | 26.7 |
| | CDS | Single Name - Industrial | 18.7 |
| | CDS | iTraxx - Europe | 24.2 |
| | CDS | iTraxx - High Vol | 97.5 |
| | CDS | iTraxx - Non-Financials | 36.4 |
| | CDS | iTraxx - Financials Sen | 34.1 |
| | CDS | iTraxx - Financials Sub | 56.9 |
| | CDS | iTraxx - Crossover 5Y | 60.8 |
| | CDS | Sovereign - DE | 0.8 |
| | CDS | Sovereign - FR | 2.5 |
| | CDS | Sovereign - IT | 13.7 |
| | CDS | Sovereign - JP | -0.8 |

Note: Interest rate, bond yield and CDS shocks expressed in basis points. Other shocks expressed in percentages.

# Table B: Shock sizes for all factors and distributions – average of stress direction "up" and "down"

| | | | | | | Value at Risk (VaR) - Avg(up,down) | | | Expected Shortfall (ES) - Avg(up,down) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Start sample | End sample | historical minimum | historical maximum | $p_1$ = 0.99 non-parametric | $p_2$ = 0.999 non-parametric | Multiplier ($p_2/p_1$) non-parametric | $p_1$ = 0.99 non-parametric | $p_2$ = 0.999 non-parametric | Multiplier ($p_2/p_1$) non-parametric |
| Interest 1M | EUR | 27/01/2003 | 19/10/2015 | -53.03 | 53.74 | 14.9 | 36.4 | 2.5 | 25.3 | 40.6 | 1.6 |
| Interest 1M | USD | 02/01/1990 | 19/10/2015 | -77.98 | 159.10 | 22.2 | 59.0 | 2.8 | 37.5 | 80.0 | 2.2 |
| Interest 1M | GBP | 02/01/1990 | 19/10/2015 | -176.78 | 119.32 | 26.4 | 70.8 | 2.7 | 44.8 | 114.1 | 2.5 |
| Interest 1M | CHF | 02/01/1990 | 19/10/2015 | -77.34 | 124.69 | 31.1 | 60.1 | 2.0 | 43.5 | 74.1 | 1.7 |
| Interest 3M | EUR | 31/12/1998 | 19/10/2015 | -50.63 | 54.59 | 7.2 | 14.7 | 2.1 | 11.5 | 25.8 | 2.2 |
| Interest 3M | USD | 02/01/1990 | 19/10/2015 | -59.40 | 80.61 | 18.6 | 42.6 | 2.3 | 28.5 | 49.9 | 1.8 |
| Interest 3M | GBP | 02/01/1990 | 19/10/2015 | -150.61 | 70.71 | 18.3 | 50.4 | 2.7 | 33.1 | 71.2 | 2.1 |
| Interest 3M | CHF | 02/01/1990 | 19/10/2015 | -86.50 | 123.74 | 22.6 | 43.6 | 2.0 | 32.9 | 61.4 | 1.9 |
| Interest 1Y | DE | 10/01/1995 | 16/10/2015 | -65.20 | 37.34 | 13.0 | 23.7 | 1.8 | 17.8 | 26.4 | 1.5 |
| Interest 1Y | US | 02/01/1990 | 16/10/2015 | -55.90 | 69.04 | 19.7 | 34.9 | 1.8 | 26.9 | 45.5 | 1.7 |
| Interest 1Y | UK | 04/01/1994 | 16/10/2015 | -49.21 | 111.58 | 17.4 | 39.9 | 2.3 | 27.0 | 53.5 | 1.9 |
| Interest 1Y | CH | 14/10/2013 | 16/10/2015 | -39.74 | 45.82 | 23.5 | 38.7 | 1.6 | 29.3 | 41.8 | 1.4 |
| Interest 5Y | DE | 07/08/1990 | 16/10/2015 | -33.66 | 42.00 | 18.1 | 27.4 | 1.5 | 22.2 | 31.3 | 1.4 |
| Interest 5Y | US | 02/01/1990 | 16/10/2015 | -58.92 | 58.31 | 23.7 | 34.5 | 1.5 | 29.0 | 40.8 | 1.4 |
| Interest 5Y | UK | 01/01/1992 | 16/10/2015 | -84.85 | 57.84 | 20.3 | 40.2 | 2.0 | 28.7 | 50.8 | 1.8 |
| Interest 5Y | CH | 10/08/1994 | 16/10/2015 | -46.24 | 60.81 | 12.4 | 29.0 | 2.3 | 18.0 | 34.2 | 1.9 |
| Interest 10Y | DE | 02/01/1990 | 16/10/2015 | -42.99 | 41.15 | 17.0 | 26.8 | 1.6 | 21.2 | 31.5 | 1.5 |
| Interest 10Y | US | 02/01/1990 | 16/10/2015 | -66.98 | 47.52 | 22.3 | 33.5 | 1.5 | 27.1 | 38.5 | 1.4 |
| Interest 10Y | UK | 02/01/1990 | 16/10/2015 | -74.95 | 46.81 | 20.6 | 39.9 | 1.9 | 28.2 | 47.1 | 1.7 |
| Interest 10Y | CH | 16/02/1994 | 16/10/2015 | -25.60 | 29.42 | 13.1 | 22.3 | 1.7 | 16.8 | 24.0 | 1.4 |
| Long | CA | 02/01/1990 | 15/10/2015 | -45.11 | 54.73 | 20.4 | 33.6 | 1.6 | 26.1 | 38.2 | 1.5 |
| Long | CH | 16/02/1994 | 16/10/2015 | -25.60 | 29.42 | 13.1 | 22.3 | 1.7 | 16.8 | 24.0 | 1.4 |
| Long | DE | 02/01/1990 | 16/10/2015 | -42.99 | 41.15 | 17.0 | 26.8 | 1.6 | 21.2 | 31.5 | 1.5 |
| Long | FR | 02/01/1990 | 16/10/2015 | -49.78 | 41.58 | 18.6 | 32.0 | 1.7 | 23.5 | 36.5 | 1.6 |
| Long | IT | 07/05/1993 | 16/10/2015 | -112.85 | 67.46 | 26.1 | 54.1 | 2.1 | 37.6 | 69.2 | 1.8 |
| Long | JP | 02/01/1990 | 16/10/2015 | -76.37 | 54.59 | 15.9 | 29.4 | 1.8 | 22.4 | 40.0 | 1.8 |
| Long | UK | 02/01/1990 | 16/10/2015 | -74.95 | 46.81 | 20.6 | 39.9 | 1.9 | 28.2 | 47.1 | 1.7 |
| Long | US | 02/01/1990 | 16/10/2015 | -66.98 | 47.52 | 22.3 | 33.5 | 1.5 | 27.1 | 38.5 | 1.4 |
| Medium | CA | 02/01/1990 | 15/10/2015 | -81.18 | 76.23 | 25.0 | 44.0 | 1.8 | 32.9 | 52.7 | 1.6 |
| Medium | CH | 10/08/1994 | 16/10/2015 | -46.24 | 60.81 | 12.4 | 29.0 | 2.3 | 18.0 | 34.2 | 1.9 |
| Medium | DE | 07/08/1990 | 16/10/2015 | -33.66 | 42.00 | 18.1 | 27.4 | 1.5 | 22.2 | 31.3 | 1.4 |
| Medium | FR | 06/08/1990 | 16/10/2015 | -49.36 | 47.80 | 19.5 | 32.2 | 1.6 | 24.9 | 39.0 | 1.6 |
| Medium | IT | 07/05/1993 | 16/10/2015 | -134.63 | 98.15 | 31.5 | 70.4 | 2.2 | 46.8 | 84.0 | 1.8 |
| Medium | JP | 02/01/1990 | 16/10/2015 | -58.12 | 61.38 | 14.8 | 29.2 | 2.0 | 20.9 | 39.8 | 1.9 |
| Medium | UK | 01/01/1992 | 16/10/2015 | -84.85 | 57.84 | 20.3 | 40.2 | 2.0 | 28.7 | 50.8 | 1.8 |
| Medium | US | 02/01/1990 | 16/10/2015 | -58.92 | 58.31 | 23.7 | 34.5 | 1.5 | 29.0 | 40.8 | 1.4 |
| Short | CA | 07/07/1997 | 15/10/2015 | -54.87 | 75.24 | 17.8 | 39.1 | 2.2 | 26.7 | 50.5 | 1.9 |
| Short | CH | 14/10/2013 | 16/10/2015 | -39.74 | 45.82 | 23.5 | 38.7 | 1.6 | 29.3 | 41.8 | 1.4 |
| Short | DE | 10/01/1995 | 16/10/2015 | -65.20 | 37.34 | 13.0 | 23.7 | 1.8 | 17.8 | 26.4 | 1.5 |
| Short | FR | 02/01/1990 | 15/10/2015 | -91.92 | 84.85 | 23.5 | 54.5 | 2.3 | 36.0 | 68.6 | 1.9 |
| Short | IT | 05/09/1994 | 15/10/2015 | -219.06 | 290.62 | 38.5 | 96.4 | 2.5 | 61.6 | 125.4 | 2.0 |
| Short | JP | 14/12/1999 | 15/10/2015 | -17.25 | 16.40 | 6.4 | 13.4 | 2.1 | 9.3 | 14.9 | 1.6 |
| Short | UK | 04/01/1994 | 16/10/2015 | -49.21 | 111.58 | 17.4 | 39.9 | 2.3 | 27.0 | 53.5 | 1.9 |
| Short | US | 02/01/1990 | 16/10/2015 | -55.90 | 69.04 | 19.7 | 34.9 | 1.8 | 26.9 | 45.5 | 1.7 |
| Certificate | EEX EU Emission Allowa | 01/04/2008 | 19/10/2015 | -45.93 | 40.26 | 12.5 | 27.3 | 2.2 | 17.3 | 30.6 | 1.8 |
| Coal | Rotterdam | 17/07/2006 | 19/10/2015 | -27.62 | 26.13 | 6.3 | 15.7 | 2.5 | 10.4 | 19.2 | 1.8 |
| Agri | Wheat | 14/05/2012 | 19/10/2015 | -13.67 | 10.88 | 6.4 | 8.5 | 1.3 | 7.5 | 10.7 | 1.5 |
| Agri | Corn | 02/01/2002 | 19/10/2015 | -24.71 | 16.98 | 5.2 | 14.5 | 2.9 | 8.6 | 17.2 | 2.0 |
| Freight | Europe-Asia | 31/12/1993 | 19/10/2015 | -11.86 | 12.20 | 4.2 | 8.0 | 1.9 | 5.9 | 9.7 | 1.7 |
| Metal | Aluminium | 12/07/1993 | 19/10/2015 | -18.26 | 19.70 | 4.7 | 9.4 | 2.0 | 7.0 | 14.2 | 2.0 |
| Natural Gas | TTF NL | 05/01/2004 | 19/10/2015 | -88.51 | 641.89 | 23.5 | 59.0 | 2.5 | 36.8 | 93.5 | 2.5 |
| Natural Gas | NG1 | 03/04/1990 | 19/10/2015 | -41.22 | 58.20 | 13.0 | 25.7 | 2.0 | 18.5 | 35.2 | 1.9 |
| Natural Gas | Henry Hub | 01/11/1993 | 19/10/2015 | -83.47 | 244.91 | 18.4 | 62.3 | 3.3 | 32.7 | 101.1 | 3.0 |
| Gas Liquid | Ethane | 20/04/1992 | 19/10/2015 | -41.88 | 75.41 | 11.4 | 25.0 | 2.2 | 16.7 | 34.0 | 2.0 |
| Oil | WTI | 02/01/1990 | 19/10/2015 | -43.75 | 30.52 | 9.6 | 18.8 | 2.0 | 13.3 | 21.2 | 1.6 |
| Oil | Brent | 02/01/1990 | 19/10/2015 | -27.28 | 19.43 | 6.8 | 14.0 | 2.1 | 9.7 | 17.7 | 1.8 |
| Power | Phelix | 02/07/2012 | 19/10/2015 | -27.09 | 55.02 | 9.7 | 28.5 | 2.9 | 17.0 | 36.3 | 2.1 |
| Soft Com | Coffee | 31/12/2001 | 19/10/2015 | -14.15 | 17.94 | 7.1 | 10.6 | 1.5 | 8.7 | 12.2 | 1.4 |
| Consumer | Stoxx 600 Europe | 31/12/1991 | 15/10/2015 | -8.22 | 19.50 | 3.9 | 7.4 | 1.9 | 5.2 | 8.9 | 1.7 |
| Energy | Stoxx 600 Europe | 02/01/1990 | 16/10/2015 | -13.23 | 18.26 | 5.2 | 10.3 | 2.0 | 7.2 | 12.7 | 1.8 |
| Health | Stoxx 600 Europe | 02/01/1990 | 16/10/2015 | -9.19 | 12.94 | 4.2 | 7.6 | 1.8 | 5.5 | 8.5 | 1.5 |
| Financial | Stoxx 600 Europe | 02/01/1990 | 16/10/2015 | -14.37 | 25.55 | 6.3 | 12.5 | 2.0 | 9.0 | 15.4 | 1.7 |
| Comm | Stoxx 600 Europe | 02/01/1990 | 16/10/2015 | -12.49 | 14.64 | 5.6 | 9.2 | 1.6 | 7.1 | 10.6 | 1.5 |
| Tech | Stoxx 600 Europe | 02/01/1990 | 16/10/2015 | -15.87 | 16.44 | 7.4 | 12.2 | 1.6 | 9.5 | 13.5 | 1.4 |
| Utility | Stoxx 600 Europe | 02/01/1990 | 16/10/2015 | -11.55 | 23.38 | 4.0 | 8.6 | 2.2 | 5.6 | 10.1 | 1.8 |
| Material | Stoxx 600 Europe | 02/01/1990 | 16/10/2015 | -13.56 | 17.14 | 5.4 | 10.8 | 2.0 | 7.4 | 12.5 | 1.7 |
| Industrial | Stoxx 600 Europe | 02/01/1990 | 16/10/2015 | -12.44 | 14.64 | 4.7 | 8.5 | 1.8 | 6.4 | 10.8 | 1.7 |
| Index | DAX30 | 02/01/1990 | 16/10/2015 | -11.80 | 16.50 | 5.7 | 9.8 | 1.7 | 7.6 | 11.6 | 1.5 |
| Index | CAC40 | 02/01/1990 | 19/10/2015 | -12.54 | 16.16 | 5.2 | 9.2 | 1.8 | 6.7 | 10.9 | 1.6 |
| Index | FTSE100 | 02/01/1990 | 16/10/2015 | -12.28 | 14.19 | 4.3 | 7.7 | 1.8 | 5.8 | 9.6 | 1.7 |
| Vola | VSTOXX 1M | 24/10/2006 | 19/10/2015 | -35.14 | 108.33 | 41.0 | 60.4 | 1.4 | 50.2 | 65.6 | 1.3 |
| Dividend | DAX30 | 14/04/2005 | 19/10/2015 | -15.34 | 15.60 | 5.9 | 12.5 | 2.2 | 8.1 | 13.8 | 1.7 |
| Dividend | CAC40 | 20/05/2005 | 19/10/2015 | -13.80 | 24.55 | 5.9 | 11.9 | 2.0 | 8.6 | 13.6 | 1.6 |
| Dividend | FTSE100 | 10/05/2005 | 19/10/2015 | -32.75 | 57.26 | 8.2 | 25.3 | 3.1 | 14.5 | 33.0 | 2.3 |
| FX | USD | 04/01/1999 | 16/10/2015 | -6.48 | 6.13 | 2.4 | 3.4 | 1.4 | 2.9 | 4.5 | 1.6 |
| FX | GBP | 04/01/1999 | 16/10/2015 | -3.69 | 5.02 | 1.8 | 3.5 | 1.9 | 2.4 | 3.7 | 1.6 |
| FX | CHF | 04/01/1999 | 16/10/2015 | -4.49 | 11.97 | 1.6 | 3.8 | 2.5 | 2.3 | 4.9 | 2.2 |
| FX | RUB | 04/01/1999 | 16/10/2015 | -14.13 | 33.09 | 3.1 | 7.0 | 2.2 | 5.0 | 11.0 | 2.2 |
| FX | BRL | 13/01/2000 | 16/10/2015 | -17.97 | 21.98 | 4.6 | 10.6 | 2.4 | 6.7 | 13.8 | 2.1 |
| CDS | Single Name - Consumer | 05/03/2007 | 17/10/2015 | -76.99 | 87.17 | 23.0 | 54.9 | 2.5 | 35.3 | 65.2 | 1.8 |
| CDS | Single Name - Energy | 27/04/2005 | 16/10/2015 | -72.10 | 91.63 | 11.0 | 47.3 | 3.8 | 23.7 | 58.4 | 2.2 |
| CDS | Single Name - Health | | | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| CDS | Single Name - Financial | 14/09/2007 | 17/10/2015 | -103.77 | 111.22 | 31.7 | 75.6 | 2.3 | 49.3 | 88.2 | 1.7 |
| CDS | Single Name - Comm | 09/03/2007 | 17/10/2015 | -105.34 | 92.54 | 26.5 | 58.7 | 2.3 | 40.9 | 72.4 | 1.8 |
| CDS | Single Name - Tech | 23/05/2008 | 19/10/2015 | -35.89 | 49.19 | 12.6 | 36.8 | 3.0 | 22.2 | 38.9 | 1.7 |
| CDS | Single Name - Utility | 16/02/2008 | 19/10/2015 | -38.72 | 45.00 | 13.0 | 34.4 | 3.4 | 21.7 | 39.0 | 1.8 |
| CDS | Single Name - Material | 01/03/2008 | 17/10/2015 | -164.45 | 146.86 | 45.8 | 115.3 | 2.5 | 71.0 | 130.9 | 1.8 |
| CDS | Single Name - Industrial | 02/07/2007 | 18/10/2015 | -171.08 | 202.28 | 28.5 | 111.2 | 2.8 | 59.3 | 129.6 | 1.9 |
| CDS | iTraxx - Europe | 21/03/2005 | 16/10/2015 | -55.82 | 32.30 | 15.1 | 29.3 | 2.0 | 20.5 | 36.5 | 1.8 |
| CDS | iTraxx - High Vol | 21/03/2005 | 16/10/2015 | -74.10 | 64.87 | 26.2 | 46.9 | 1.8 | 34.6 | 58.7 | 1.7 |
| CDS | iTraxx - Non-Financials | 21/03/2005 | 16/10/2015 | -653.01 | 109.03 | 16.0 | 73.8 | 4.7 | 54.7 | 301.5 | 4.7 |
| CDS | iTraxx - Financials Sen | 21/03/2005 | 16/10/2015 | -89.29 | 74.16 | 23.1 | 44.7 | 1.9 | 32.5 | 56.9 | 1.7 |
| CDS | iTraxx - Financials Sub | 21/03/2005 | 16/10/2015 | -125.60 | 93.47 | 37.4 | 73.9 | 2.0 | 52.0 | 90.2 | 1.7 |
| CDS | iTraxx - Crossover 5Y | 21/03/2005 | 16/10/2015 | -321.66 | 291.29 | 57.9 | 130.4 | 2.3 | 84.8 | 190.1 | 2.2 |
| CDS | Sovereign - DE | 08/01/2004 | 19/10/2015 | -20.25 | 15.51 | 7.4 | 13.1 | 1.8 | 10.0 | 15.9 | 1.6 |
| CDS | Sovereign - FR | 16/08/2005 | 19/10/2015 | -42.00 | 32.27 | 14.9 | 26.8 | 1.8 | 19.6 | 30.6 | 1.6 |
| CDS | Sovereign - IT | 20/01/2004 | 19/10/2015 | -107.98 | 102.04 | 38.1 | 74.9 | 2.0 | 54.7 | 83.5 | 1.5 |
| CDS | Sovereign - JP | 01/01/2004 | 19/10/2015 | -42.71 | 40.59 | 9.5 | 25.1 | 2.6 | 15.2 | 33.8 | 2.2 |
| CDS | Sovereign - UK | 13/11/2007 | 19/10/2015 | -31.22 | 26.73 | 9.9 | 20.1 | 2.0 | 13.8 | 23.3 | 1.7 |
| CDS | Sovereign - US | 11/12/2007 | 19/10/2015 | -17.96 | 22.49 | 7.2 | 15.2 | 2.1 | 10.7 | 18.4 | 1.7 |

Note: Interest rate, bond yield and CDS shocks expressed in basis points. Other shocks expressed in percentages.

## Table C: Degree of freedom parameter estimates from t-distributions for all factors

| | | | t - distribution degrees of freedom |
|---|---|---|---|
| Interest | Interest 1M | EUR | 1.6 |
| | Interest 1M | USD | 0.6 |
| | Interest 1M | GBP | 0.6 |
| | Interest 1M | CHF | 0.6 |
| | Interest 3M | EUR | 1.2 |
| | Interest 3M | USD | 0.6 |
| | Interest 3M | GBP | 0.7 |
| | Interest 3M | CHF | 0.7 |
| | Interest 1Y | DE | 2.6 |
| | Interest 1Y | US | 1.9 |
| | Interest 1Y | UK | 2.6 |
| | Interest 1Y | CH | 1.4 |
| | Interest 5Y | DE | 4.2 |
| | Interest 5Y | US | 5.0 |
| | Interest 5Y | UK | 3.9 |
| | Interest 5Y | CH | 3.6 |
| | Interest 10Y | DE | 4.9 |
| | Interest 10Y | US | 6.2 |
| | Interest 10Y | UK | 4.5 |
| | Interest 10Y | CH | 4.3 |
| Bond | Long | CA | 4.7 |
| | Long | CH | 4.3 |
| | Long | DE | 4.9 |
| | Long | FR | 4.4 |
| | Long | IT | 2.7 |
| | Long | JP | 2.7 |
| | Long | UK | 4.5 |
| | Long | US | 6.2 |
| | Medium | CA | 3.5 |
| | Medium | CH | 3.6 |
| | Medium | DE | 4.2 |
| | Medium | FR | 3.8 |
| | Medium | IT | 2.4 |
| | Medium | JP | 2.2 |
| | Medium | UK | 3.9 |
| | Medium | US | 5.0 |
| | Short | CA | 1.8 |
| | Short | CH | 1.4 |
| | Short | DE | 2.6 |
| | Short | FR | 1.6 |
| | Short | IT | 1.5 |
| | Short | JP | 1.0 |
| | Short | UK | 2.6 |
| | Short | US | 1.9 |

| | | | t - distribution degrees of freedom |
|---|---|---|---|
| Commodity | Certificate | EEX EU Emission Allowance | 1.7 |
| | Coal | Rotterdam | 1.7 |
| | Agri | Wheat | 1.5 |
| | Agri | Corn | 5.3 |
| | Freight | Europe-Asia | 2.5 |
| | Metal | Aluminium | 3.8 |
| | Natural Gas | NG1 | 2.7 |
| | Gas Liquid | Ethane | 3.7 |
| | Oil | WTI | 2.5 |
| | Oil | Brent | 3.3 |
| | Power | Phelix | 3.8 |
| | Soft Com | Coffee | 2.2 |
| Equity | Consumer | Stoxx 600 Europe | 4.5 |
| | Energy | Stoxx 600 Europe | 3.5 |
| | Health | Stoxx 600 Europe | 3.6 |
| | Financial | Stoxx 600 Europe | 3.9 |
| | Comm | Stoxx 600 Europe | 2.6 |
| | Tech | Stoxx 600 Europe | 3.5 |
| | Utility | Stoxx 600 Europe | 2.6 |
| | Material | Stoxx 600 Europe | 3.9 |
| | Industrial | Stoxx 600 Europe | 3.0 |
| | Index | DAX30 | 3.1 |
| | Index | CAC40 | 3.4 |
| | Index | FTSE100 | 4.0 |
| | Vola | VSTOXX 1M | 3.6 |
| | Dividend | DAX30 | 4.2 |
| | Dividend | CAC40 | 3.3 |
| | Dividend | FTSE100 | 3.3 |
| FX | FX | USD | 2.3 |
| | FX | GBP | 5.9 |
| | FX | CHF | 4.8 |
| | FX | RUB | 2.0 |
| | FX | BRL | 2.5 |
| CDS | CDS | Single Name - Consumer | 3.4 |
| | CDS | Single Name - Energy | 0.9 |
| | CDS | Single Name - Health | 1.1 |
| | CDS | Single Name - Financial | - |
| | CDS | Single Name - Comm | - |
| | CDS | Single Name - Tech | - |
| | CDS | Single Name - Utility | - |
| | CDS | Single Name - Material | - |
| | CDS | Single Name - Industrial | - |
| | CDS | iTraxx - Europe | - |
| | CDS | iTraxx - High Vol | - |
| | CDS | iTraxx - Non-Financials | - |
| | CDS | iTraxx - Financials Sen | - |
| | CDS | iTraxx - Financials Sub | - |
| | CDS | iTraxx - Crossover 5Y | - |
| | CDS | Sovereign - DE | - |
| | CDS | Sovereign - FR | - |
| | CDS | Sovereign - IT | - |
| | CDS | Sovereign - JP | - |
| | CDS | Sovereign - UK | - |
| | CDS | Sovereign - US | - |