A review of the Solvency II equity shock

Hervé Andrès
Pierre-Edouard Arrouy
Alexandre Boumezoued
Eric Serant

In the comparative study on market and credit risk modelling for 2019, EIOPA observes that the equity risk shocks applied by the surveyed Internal Models (IMs) are higher overall than the Standard Formula (SF).[1]

Moreover, the study exhibits a large dispersion of the values of these IM equity risk shocks. This may appear as a paradox since universal time series are used for the major indices and a similar one-year view on risk is considered. In this paper, we conduct a review of the SF shocks by providing a common basis of calibration for the one-year view, while also exploring a new approach that takes into account the long-term nature of the investments within insurance portfolios.

The equity risk sub-module of the Solvency Capital Requirement (SCR) market risk module is defined in the Article 105 of the Solvency II Directive as 'the sensitivity of the values of assets, liabilities and financial instruments to changes in the level or in the volatility of market prices of equities.' In the SF, the equity risk sub-module only captures changes in the level of equity prices (and, for example, not in the volatility of prices). In this paper, we will discuss the modelling of equity level risk only.

The equity risk sub-module aims at quantifying the impact of a sudden drop in the equity market on the insurer balance sheet. Thus, the capital requirement for equity risk is computed as the loss in own funds incurred by an equity shock. The methodology to determine this equity shock is detailed in the Delegated Regulation of Solvency II.[2] In the first part of this paper, we review this methodology as well as the upstream calibration that has been performed by EIOPA. A recalibration is also proposed based on up-to-date historical series and benchmark models, yielding an equity shock close to the ones exhibited in EIOPA's comparative study.

At a refined time-step (intra-year in general), the stock market is known to be very volatile and has already notched up significant crashes in recent decades. However, after crisis, the stock market tends to go back in average to its pre-crisis level and even above after some time: this is referred to as the mean-reverting behaviour of the stock market. Due to this phenomenon and the long-term positions of insurance portfolios, it can be expected that in average again, if a shock occurs, it will be mitigated in the future thanks to the mean-reverting behaviour of the stock market.

These ideas are actually not new. Indeed, the Solvency II Directive already provides a specific treatment of three components, namely strategic equity, long-term equity investments, and the duration-based approach (see further discussion in this paper), that take into account the long-term nature of equity investments, leading to lower equity shocks. Under Solvency II, specific conditions must be met to apply those shocks, therefore a limited share of equity investments and insurance undertakings are eligible and thus, standard equity shocks remain predominant.

In this paper, we explore a new approach for the estimation of the equity risk charge based on the ideas of mean-reversion of the stock markets and multi-year holding of equity assets by insurance undertakings. This approach allows an insurer to compute lower shocks than the SF approach and could therefore be investigated within the scope of an IM.

[1] EIOPA. Market and Credit Risk Comparative Study YE2019. Retrieved 14 May 2021 from https://www.eiopa.europa.eu/market-and-credit-risk-comparative-study-ye2019_en.

[2] Commission Delegated Regulation (EU) 2015/35 of 10 October 2014 supplementing Directive 2009/138/EC of the European Parliament and of the Council on the taking-up and pursuit of the business of Insurance and Reinsurance (Solvency II). Consolidated text retrieved 26 May 2021 from http://publications.europa.eu/resource/cellar/9addd91b-a222-11eb-b85c-01aa75ed71a1.0014.03/DOC_1.

Standard Formula shock

The Solvency II Directive provides several levels of equity risk shock depending on the type of asset classes or the nature of the insurer's investment. For the most common investments, the standard approach applies, while for investments having some specific characteristics, a reduced shock can be used.

'STANDARD' APPROACH

In the standard approach, a distinction is made between type 1 equities and type 2 equities.[3] The type 1 category covers equities listed in regulated markets which are members of the EEA or the OECD, and the type 2 category covers all other kinds of equities. The idea behind this distinction is to reflect the fact that type 2 equities are riskier than type 1 equities. As a consequence, the shock for type 2 equities is more adverse than for type 1 equities. These shocks are specified by the Solvency II Directive as follows:

$$Shock_{Type\ 1} = 39\% + SA$$

$$Shock_{Type\ 2} = 49\% + SA$$

where SA is the symmetric adjustment. The symmetric adjustment is an adjustment factor designed to prevent pro-cyclical effects of Solvency Capital Requirements (in particular, to avoid a rise in the equity risk charge in the middle of a crisis). It is defined by:

$$SA = \frac{1}{2}\left(\frac{CI - AI}{AI} - 8\%\right)$$

where:

- CI is the current level of an equity index representative of the equities held by the insurance undertaking
- AI is the equally weighted average of the daily levels of the equity index over the last 36 months

This formula guarantees that the shocks will be raised in times of rising markets and lowered in times of falling equity markets. Note that this adjustment is floored at -10% and capped at +10%, so that the equity shock lies within a band of 10% either side of the standard shock. Note that the Consultation Paper on the Opinion on the 2020 review of Solvency II,[4] and more recently the Opinion on the 2020 Review of Solvency II,[5] suggested to enlarge the abovementioned corridor to +/-17% and to floor the overall capital charge at 22%.

The standard shocks of 39% and 49% result from a calibration performed by EIOPA and detailed in a Calibration Paper published in 2010.[6] The calibration of the shock for type 1 equities relies on daily data from the MSCI World Developed Index, spanning a period of 36 years (from 1973 to 2009). Annual returns are calculated using a rolling one-year window in order to make use of the greatest possible data volume. Then, a normal distribution is fitted on these annual returns and the 0.5% Value-at-Risk (VaR) is computed, yielding the value of 39%. EIOPA recognizes in this calibration paper that the normal distribution assumption is not in line with the empirical distribution of the annual returns since the empirical distribution presents fatter tails in comparison. Therefore, a refined analysis is performed and a more conservative value of 45% is also mentioned. Despite this, the value of 39% has finally been retained within Solvency II. A similar study has been conducted for type 2 equities and a shock of 55% has been proposed. Again, it appears that this value has been revised downwards in the final text.

[3] Since an amendment of 2017, there are actually four types of equity investments. The two new types are qualifying infrastructure equities and infrastructure corporate equities. Because of their specificities, we omit them in this paper.

[4] EIOPA. Consultation Paper on the Opinion on the 2020 review of Solvency II, October 2019, found at: https://www.eiopa.europa.eu/sites/default/files/solvency_ii/eiopa-bos-20-749-opinion-2020-review-solvency-ii.pdf.

[5] EIOPA. Opinion on the 2020 review of Solvency II, December 2020, found at: https://www.eiopa.europa.eu/sites/default/files/publications/consultations/eiopa-bos-19-465_cp_opinion_2020_review.pdf.

[6] CEIOPS. Solvency II Calibration paper (CEIOPS-SEC-40-10). Retrieved 26 May 2021 from https://www.eiopa.europa.eu/sites/default/files/publications/submissions/ceiops-calibration-paper-solvency-ii.pdf.

REVISED STANDARD SHOCK

We propose to explore the recalibration of the standard shock of 39% applying to type 1 equities using more recent data and some benchmark models. For this purpose, we rely on monthly data from the Euro Stoxx 50 Index starting in May 1987 and ending in December 2020. We compute annual discounted log-returns using a rolling one-year window in line with the EIOPA approach and we consider the following set of models:

- Normal distribution
- Gaussian mixture distribution
- Ornstein-Uhlenbeck model, specified by the following stochastic differential equation:

$$dX_t = (\theta_1 - \theta_2 X_t)dt + \theta_3 dW_t$$

where X_t is the annual discounted log-return at time t and W_t is a Brownian motion.

The first model is a natural benchmark, while the second approach allows a refinement of the Gaussian assumption by reflecting different possible modes. Finally, the Ornstein-Uhlenbeck model takes into account mean-reversion. Note that for the first two models, the annual discounted log-returns are assumed to be independent while in the last model, they are correlated.

Once the models are fitted, the 0.5% VaRs are computed for each model. Different time periods are tested in order to measure the sensitivity to the historical data set used for the calibration. The shocks obtained are depicted in Figure 1, and are compared to measuring the empirical VaR.

As expected, including or not including, the 2008 crisis has a significant impact on the resulting shocks. Focusing on the results when the 2008 crisis is included, we obtain values between 40% and 50% which are higher than the standard shock but comparable to the shocks exhibited in EIOPA's comparative study on market and credit risk modelling that surveyed IM practices (see Figure 2). Furthermore, it appears that using benchmark models such as the Normal distribution or the Ornstein-Uhlenbeck process, one recovers similar orders of magnitude to the SF shock. Finally, we also see that considering the most recent experience, shocks are lower than the SF.

FIGURE 1: EQUITY SHOCKS FOR SEVERAL MODELS CALIBRATED ON DIFFERENT TIME PERIODS

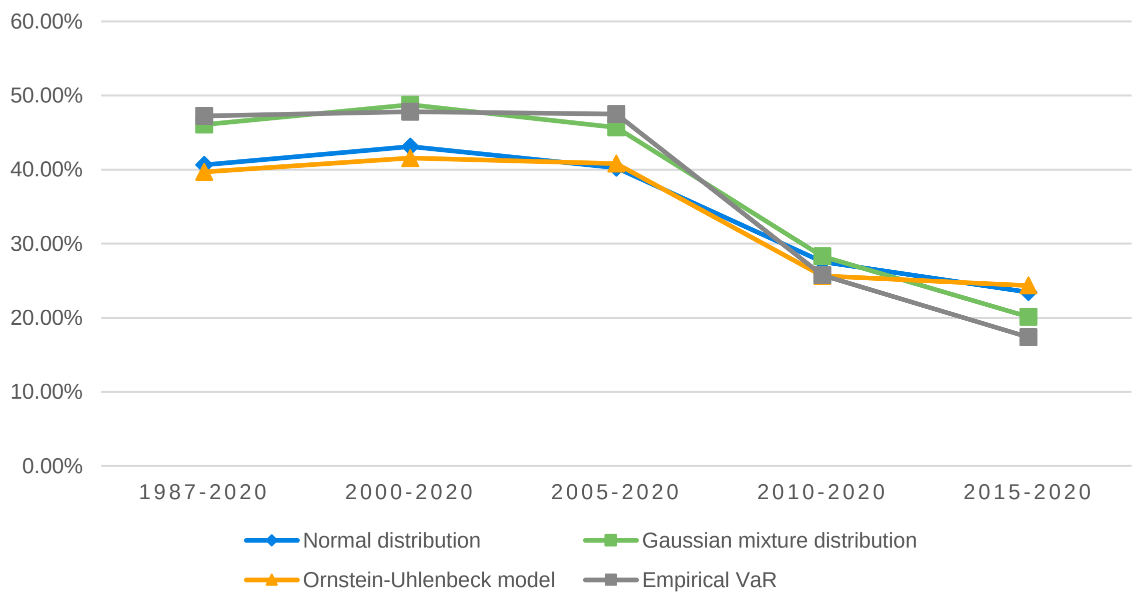
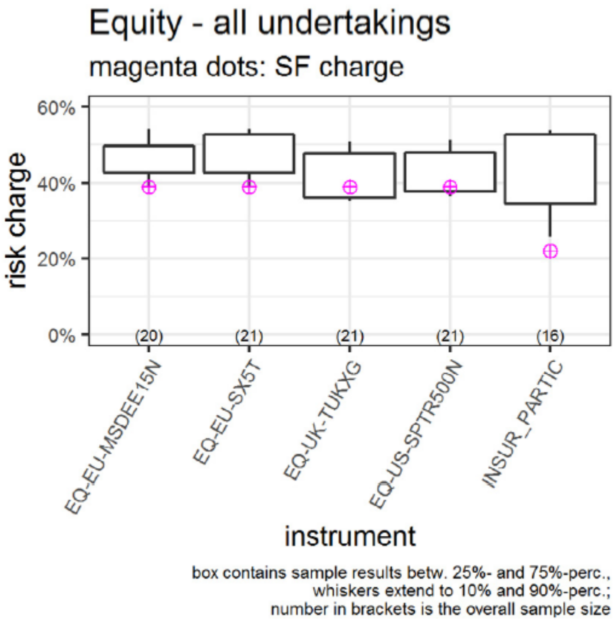
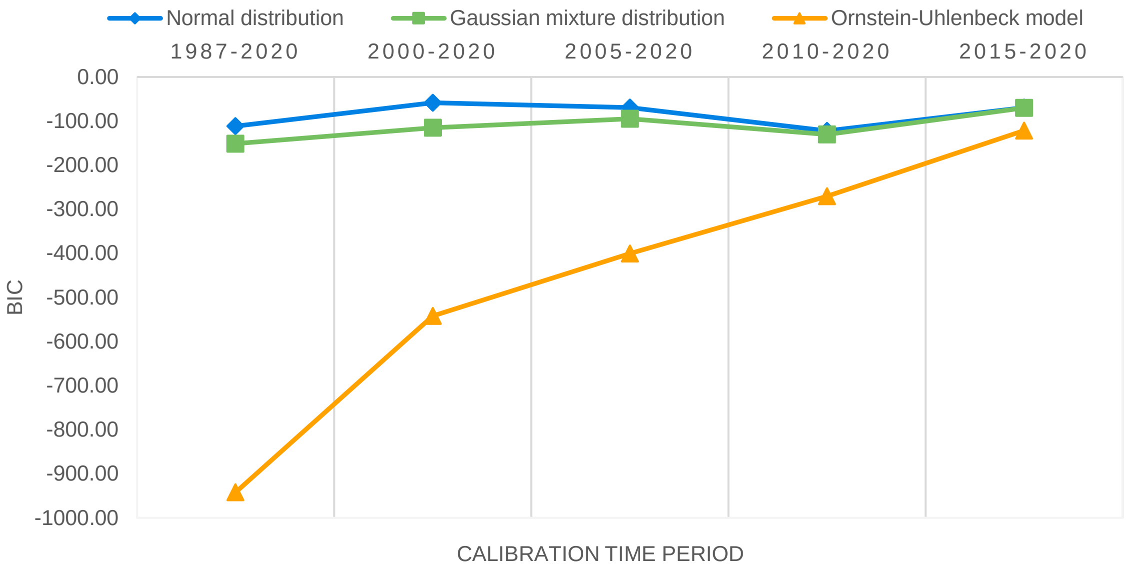


FIGURE 2: BOXPLOTS OF EQUITY SHOCKS FOR SEVERAL INDICES. EACH BOXPLOT REPRESENTS THE DISTRIBUTION OF THE SHOCKS SHARED BY THE SURVEYED UNDERTAKINGS. (SOURCE: EIOPA'S YE2019 COMPARATIVE STUDY ON MARKET AND CREDIT RISK MODELLING)



In the light of our study, the heterogeneity in terms of results of IM for equity shocks as shown in Figure 2 is actually not so surprising since we obtain very different values for different models on a given index and at given time periods, which indicates that the shock estimation is highly model- and data-dependent. Also, it is clear that all models are not equal in terms of realism. In order to select a model over another, a selection criterion is required. The Bayesian information criterion (BIC) is an example of such selection criterion. It measures the log-likelihood of a model with a penalization for the number of parameters, so that models with a lot of parameters having a high likelihood will not necessarily be the best according to the BIC. The lower the BIC, the better the model. In Figure 3, we plot the BIC for the three considered models to derive the standard shock.

FIGURE 3: BAYESIAN INFORMATION CRITERION FOR THE DIFFERENT MODELS AND TIME PERIODS



As we can see, the Ornstein-Uhlenbeck model best describes the data set since it has by far the lower BIC, especially if we include the 2008 crisis. This indicates in particular that discounted log-returns are correlated and thus not independent. In comparison, it is worth mentioning that the use of empirical VaR implicitly assumes a form of independence. As such, as shown in Figure 1, the Ornstein-Uhlenbeck model appears as a reasonable choice in the framework of this testing, noticing that it leads to a shock close to the 39% SF shock at a one-year horizon where a large historical period is considered.

REDUCED SF SHOCKS FOR SPECIFIC INVESTMENTS

In three particular cases, a reduced shock can be applied instead of the standard approach. These three cases are:

- Strategic equity investments (SEI)
- Long-term equity investments (LTEI)
- The (DB) approach

SEIs are basically equity investments having a low volatility and for which the insurance undertaking has a clear strategy of holding its participation for a long period.[7] As such, these investments are considered less risky and a lower standard shock of 22% (without any symmetric adjustment) can be applied whether it is a type 1 or a type 2 equity. As shown in Figure 2 (rightmost boxplot), IM benchmarks show significantly higher shocks than the 22% for such instruments.

LTEIs have been introduced in the Solvency II Directive by an amendment in 2019. They are defined as equity investments meeting a certain number of conditions[8] whose main ones are:

- They are included within a portfolio assigned to cover the Best Estimate. In particular, equities assigned to cover own funds and unit linked insurance plans are not eligible.
- The total value of the LTEIs can't represent more than 50% of the insurer balance sheet.
- The average holding period exceeds five years.
- The insurance undertaking is sufficiently robust to guarantee that it won't be forced to sell these investments under stressed conditions for at least 10 years.

LTEIs are also granted a 22% lower standard shock (without any symmetric adjustment).

The DB approach can only be implemented by life insurance undertakings providing certain occupational retirement provisions or retirement benefits where the typical holding period of equity investments is assumed to be consistent with an average duration of liabilities for such business, and exceeds 12 years.[9] Under these conditions, a shock of 22% similar to the one applied to strategic investments and LTEIs can be used. Note that unlike strategic and LTEIs, the eligibility to the DB approach doesn't rely on the type of equity but on the nature of the insurer's activities. The idea behind this approach is that life insurance undertakings whose liabilities' duration is very long can make long-term investments in equities. They are therefore not exposed to the short-term volatility of these investments but rather to their long-term volatility which is considered to be lower, hence the lower shock.

To conclude this section, we summarize the various possible shocks in the SF in Table 1.

TABLE 1: EQUITY SHOCKS IN THE STANDARD FORMULA

Category	Equity type	Shock	EIOPA calibration
Standard approach	Type 1	39% + SA	45% + SA
	Type 2	49% + SA	55% + SA
SEI	All	22%	Ø
LTEI	All	22%	Ø
DB approach	All	22%	22%

[7] See Article 171 of the Delegated Regulation of Solvency II for a comprehensive definition of strategic investments.

[8] See Article 171bis of the Delegated Regulation of Solvency II for a comprehensive definition of long-term investments.

[9] See Article 304 of the Solvency II Directive for more details.

FOCUS ON THE METHODOLOGY UNDERLYING THE DB APPROACH

The calibration of the shock associated with the DB approach[10] is also mentioned in the Calibration Paper CEIOPS-SEC-40-10. In this paper, EIOPA assumes a duration of T years. As a consequence, a compounded level of confidence of $(99.5\%)^T$ (99.5% to the power T) is considered instead of 99.5% for the VaR, the underlying assumption being that the events of default are independent from one year to the next. The stock price dynamics are modelled using the Black-Scholes model:

$$dS_t = \mu S_t dt + \sigma S_t dW_t,$$

where μ is the drift parameter (corresponding to the instantaneous return of the stock) and σ the volatility parameter. For a positive drift parameter, it is expected that the stock price will grow over the long term, allowing some compensation for a possible sudden drop of the stock price. Within this model, the shock at level of confidence $(99.5\%)^T$ over a T-year horizon is given by:

$$Shock = 1 - \exp\left(\left(\mu - r - \frac{\sigma^2}{2}\right)T - \sigma\sqrt{T}\Phi^{-1}(0.995^T)\right)$$

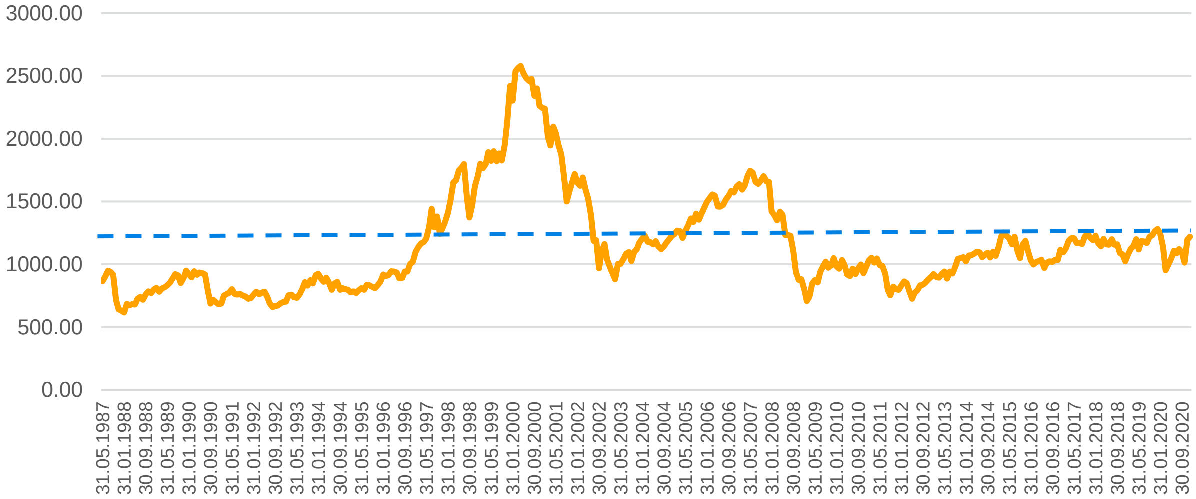
where r is the risk-free rate and Φ^{-1} the inverse of the normal cumulative distribution function. It is clear from this formula that the longer the duration, the lower the shock if $\mu > r + \frac{\sigma^2}{2}$. EIOPA chooses $\mu = 10\%$, $r = 5\%$ and σ is calibrated following the Campbell Viceira study.[11] Moreover, a floor of 22% is set on the shock. They obtain that the shock is lower than 22% for durations greater than nine years; this lower shock comes here from the natural growth of the equity as it accumulates over time and compensates the cumulative adverse deviation. As undertakings eligible for the DB approach have a duration exceeding 12 years, the shock is fixed to 22%.

Note that this approach does not seem straightforward to implement within an IM since the equity SCR must be either computed as the impact of an instantaneous shock on the own funds or as the one in two hundred years worst deviation at a one-year horizon. Besides, the confidence level $(99.5\%)^T$ cannot be linked to the reference 99.5% value overall.

LIMITS OF THE STANDARD SHOCK

We propose to explore the recalibration of equity shocks by taking into account that insurance undertakings may consider multi-year investments in the equity market and that stocks present a mean-reverting behaviour in the long term (see, for example, Fama and French[12] for a study of this effect on historical data), that a decline in stock prices is most likely to be followed by an upward price movement and vice versa as illustrated below on major indices (Figures 4, 5, and 6) for the calibration periods considered for this experiment, as discussed below.

FIGURE 4: EVOLUTION OF THE DISCOUNTED EURO STOXX 50 INDEX BETWEEN MAY 1987 AND DECEMBER 2020 ALONG WITH AN ILLUSTRATION OF LONG-TERM MEAN (BLUE DASHED LINE).



[10] To our knowledge, such study is not available for strategic and long-term equity investments (LTEIs).

[11] Campbell, J.Y. & Viceira, L.M., (2002). Strategic asset allocation: portfolio choice for long-term investors. Clarendon Lectures in Economic.

[12] Fama, E.F., & French, K.R. (1988). Permanent and temporary components of stock prices. Journal of political Economy, 96(2), 246-273.

We have seen in this first part that these aspects are actually taken into account in the Solvency II Directive through strategic/LTEIs and the DB approach. However, the criteria to be considered as strategic or LTEIs, or to be eligible to the DB approach, are quite restrictive in particular regarding strategic and long-term investments. Moreover, the methodology underlying the shock of 22% does not seem transposable to IM from some aspects:

- The independence of the stress events is not supported by any evidence.
- The Black-Scholes model is a rather simple model to describe a stock price dynamics in the real world.
- Expert judgements should be involved to determine a relevant value for a floor (here 22%).

FIGURE 5: EVOLUTION OF THE DISCOUNTED S&P 500 INDEX BETWEEN JANUARY 1990 AND DECEMBER 2013 ALONG WITH AN ILLUSTRATION OF LONG-TERM MEAN (BLUE DASHED LINE).

FIGURE 6: EVOLUTION OF THE DEFLATED CAC 40 INDEX BETWEEN APRIL 1990 AND DECEMBER 2020 ALONG WITH AN ILLUSTRATION OF THE LONG-TERM MEAN (BLUE DASHED LINE).

Besides, it appears in Figure 2 that the participants to the EIOPA survey on IMs compute a much larger shock for strategic investments within their IM than the SF. This indicates that the surveyed undertakings may have encountered challenges to design a justified model yielding a shock close to 22% within the Solvency II framework by taking into account the long-term nature of the investments.

Revisiting equity shock calibration

One main challenge in measuring the impact of long-term investments lies in its (apparent) incompatibility with the definition of the 'one-year' view on risk. Let us recall the definition of the SCR itself: 'the Solvency Capital Requirement shall correspond to the Value-at-Risk of the basic own funds of an insurance or reinsurance undertaking subject to a confidence level of 99.5% over a one-year period.' Formally, if we denote by S_t the value of the equity portfolio of an insurer at time t, then the SCR of the equity sub-module is given by:

$$SCR = VaR_{99.5\%}(S_0 - D_1 S_1) = S_0 - VaR_{0.5\%}(D_1 S_1) \quad (1)$$

where D_t is the discount factor from 0 to t. This formula measures the 0.5% worst one-year deviation of the portfolio from its initial value. This basic formalism needs further tailoring for such market risk where positions are held over a multi-year period, and where any profit or loss can be viewed over this horizon.

RISK MEASUREMENT OVER SOME TIME HORIZON

We consider a duration of $T \geq 1$ years reflecting the time during which a synthetic asset is held, and we explore the following alternative definition:

$$SCR^* = \mathbb{E}[D_T S_T] - \mathbb{E}[D_T S_T | D_1 S_1 = VaR_{0.5\%}(D_1 S_1)]. \quad (2)$$

This formula measures the deviation between the expected value of the portfolio at future time T and the expected value at time T if a shock occurred the first year. It allows a one-year risk horizon during which equity level variations can occur, to be combined with the reality of the portfolio management where here it is assumed that the asset is held up to time T, therefore measuring expected losses at the time where the sale/rebalancing is likely to occur. It is worth mentioning that contrary to the EIOPA approach for strategic equity participations, the formula (2) does not provide 'gains' related to the natural growth of equity returns since both terms are homogeneous: respectively, the unconditional and conditional discounted value of the stock at T years.

Let us now discuss the impact of mean-reversion: If the discounted portfolio value $D_t S_t$ is mean-reverting, the expectation $\mathbb{E}[D_T S_T | D_1 S_1 = VaR_{0.5\%}(D_1 S_1)]$ should converge to $\mathbb{E}[D_T S_T]$ when T becomes large and thus, the alternative definition of the SCR (denoted by SCR^* above) should converge to 0. The time at which the convergence holds depends on the so-called 'mean-reverting speed' and can be estimated on historical data as detailed in the following. Thus, formula (2) allows to capture the risk of a loss of capital at the end of the investment rather than the risk linked to the short-term volatility captured by the formula (1).

In order to compute the value of this new SCR definition, we first fit a model on the historical log-discounted index $\log D_t S_t$. The reason we do not work on annual log-returns as before is that we aim to capture the mean-reverting behaviour in the level of the discounted index and not in the returns. Once the model has been calibrated, the two expectations involved in the formula (2) are computed within the model (either by closed-form or by simulation). In this paper, we considered only the Ornstein-Uhlenbeck model we already used for the review of the standard shock. This choice is motivated by the fact that this model is mean-reverting towards the ratio θ_1/θ_2, provided that $\theta_2 > 0$.

NUMERICAL RESULTS

We rely on the same historical data as before, that is, monthly quotations of the Euro Stoxx 50 Index starting in May 1987 and ending in December 2020; but we consider also monthly series of the S&P 500 Index and the CAC 40 Index. For the CAC 40 Index, the data covers the period from April 1990 to December 2020, while for the S&P 500 Index the data covers the period from January 1990 to December 2013. More recent data for the S&P 500 Index have not been used because this index has strongly increased between 2013 and 2020, which is not satisfying for the use of a mean-reverting model. This choice has also appeared more prudent than considering the whole historical data.

In Table 2, we present the calibrated parameters of the Ornstein-Uhlenbeck model that have been obtained for each index.

TABLE 2: CALIBRATED PARAMETER VALUES FOR EACH INDEX

	Euro Stoxx 50	S&P 500	CAC 40
θ_1	1.362	0.977	2.132
θ_2	0.193	0.143	0.283
θ_3	0.188	0.149	0.190

From these parameters, one can infer the mean-reversion level of the (discounted) index by $\exp(\theta_1/\theta_2)$ as well as the mean-reverting time τ that is defined as the number of years that the discounted index takes in average to reach the mean-reversion level (up to some relative precision denoted by ϵ) after having fallen to the 0.5% VaR level for the first year; expressed as a formula we have:

$$\tau = -\frac{1}{\theta_2}\log\frac{\epsilon\theta_1}{|\theta_2 \times \log(VaR_{0.5\%}(D_1S_1)) - \theta_1|}.$$

Indeed, the expectation of the discounted log-return after some period t following the one-year shock is:

$$\mathbb{E}[X_t] = VaR_{0.5\%}(X_1)e^{-\theta_2 t} + \frac{\theta_1}{\theta_2}\left(1 - e^{-\theta_2 t}\right),$$

then the mean-reverting time τ can be obtained by solving:

$$\epsilon = \left|\frac{\mathbb{E}[X_\tau]}{\theta_1/\theta_2} - 1\right|.$$

The mean-reversion levels and mean-reverting times[13] are depicted in Table 3.

TABLE 3: MEAN-REVERSION LEVELS AND MEAN-REVERTING TIMES FOR EACH INDEX

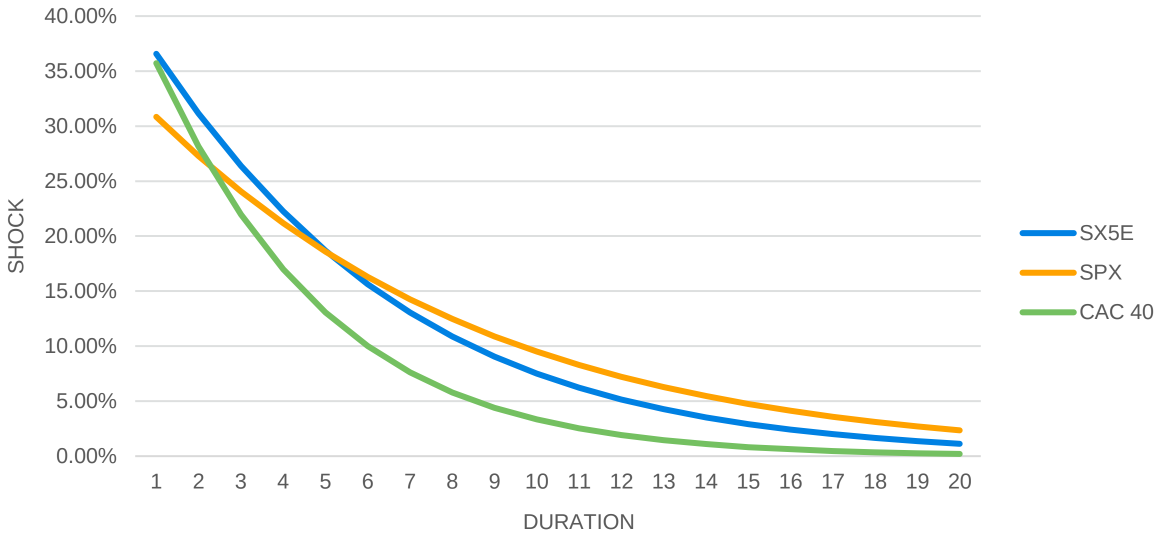
	Mean-reversion level	Mean-reverting time (in years, rounded) for $\epsilon = 0.1\%$
Euro Stoxx 50	1150	24
S&P 500	918	33
CAC 40	1887	16

Unlike formula (1), the shock (given by $SCR^*/\mathbb{E}[D_T S_T]$) depends on the level of the index at time 0. We chose to set this value to the last available quotation for each index, that is the quotation as of December 2020 (even for the S&P 500). The shocks obtained with the calibrated parameters are presented in Figure 8 for all durations T between 1 and 20 years.

We obtain lower shocks than in the SF and, as expected, these shocks become smaller when the duration increases. In particular, the decay rates are in line with the mean-reverting times computed above: for example, the shock for the CAC 40 is very close to 0 for a duration of 16 years. Besides, the shocks for the one-year duration are relatively close to the 39% standard shock and the shocks for the five-year duration are quite close to the 22% standard shock of the DB approach. As such, this experiment seems to provide a consistent framework to both values, depending on the holding period considered. We recall that this conclusion holds for this particular choice of data, model, and historical period.

[13] The mean-reverting time is calculated starting from the shock based on the unconditional mean, rather than the spot value, as at 31.12.20 in order to provide a universal value.

FIGURE 7: REVISITED SHOCKS AS A FUNCTION OF THE DURATION WITHIN THE ORNSTEIN-UHLENBECK MODEL



Concluding remarks

The Solvency II Directive offers the possibility to apply a lower shock of 22% using strategic/LTEIs or the DB approach. However, the conditions to be eligible are specific to those investments and more generally, the methodology behind these lower shocks is not straightforward to implement within IMs. This is shown in particular by the IM benchmark shocks presenting significantly higher capital charges for those investments compared to the SF.

By relying on the ideas that stock markets are mean-reverting and that the insurer holds a given equity investment for a multi-year period, we have explored a new methodology to compute the equity shocks that provides lower shocks compared to the SF standard shock.

This methodology could be of course improved in different ways. First, we didn't take dividends into account, which could lower the equity shocks obtained as far as we observed that they are strongly negatively correlated with the equity log-returns. Second, the mean-reverting models used to describe the historical data are quite simple and could be enhanced; for instance by using non-stationary models. Finally, this analysis could be extended to other types of investments, covering the range of typical insurance asset portfolio exposures.

Milliman

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CONTACT

Hervé Andrès
herve.andres@milliman.com

Pierre-Edouard Arrouy
pierre-edouard.arrouy@milliman.com

Alexandre Boumezoued
alexandre.boumezoued@milliman.com

Eric Serant
eric.serant@milliman.com