A methodology for actively managing tail risks and uncertainties

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Abstract Tail risks and uncertainties have a significant negative impact on financial institutions and the financial system. Their probability of occurrence is low (tail risk) or cannot be determined (uncertainty). One may believe that tail risks and uncertainties are unavoidable; however, this is too simplistic a view. Financial institutions and supervisory agencies can in many cases actively manage the likelihood and impact of tail risks and uncertainties. This active approach benefits from a structured methodology. The three main components of that methodology are identification, assessment and mitigation. The methodology outlined in this paper is based on the experience of risk managers across different financial institutions, supervisory agencies and non-financial institutions.

Keywords: *tail risks, uncertainties, behavioural biases, power laws, regulation*

INTRODUCTION

Tail risks and uncertainties are often perceived to be events beyond human control. That, however, is too simplistic a view, because financial institutions and supervisory agencies can take actions to reduce their probability and impact. Such an active attitude can benefit from a structured methodology. The three components of that methodology are identification, assessment and mitigation. Clearly, the structured methodology as set out in this paper is not in itself sufficient to consign tail risks and uncertainties to the past. But it does ensure that financial institutions and supervisory agencies are better prepared for extreme scenarios. This contributes to greater risk awareness and a more stable financial system.

The financial system is recurrently disturbed by major shocks such as stock market crashes, asset bubbles bursts, failing financial institutions and liquidity crises. Such shocks are the material manifestations of tail risks and uncertainties and occur more often than humans predict.[1] The root cause is often difficult to trace, even after the shock has occurred. The immediate trigger can be endogenous (eg, a sovereign default) or exogenous (eg, a terrorist attack or a natural disaster). While the initial damage may be limited, the ensuing disruption and long-term impact is generally exacerbated by irrational behaviour of economic agents and structural deficiencies in the financial system. Structural weaknesses stem from, for example, the complexity, size, mutual dependencies and homogeneity of the financial system.

Tail risks and uncertainties play a key role in regulation. The high confidence levels underlying prudential supervision frameworks imply that financial institutions and supervisory agencies need to anticipate rare events.[2] In reality, however, financial institutions and supervisory agencies may underestimate tail risks and uncertainties.[3] For this reason, they frequently play an important role in provoking financial crises and thus impair the stability of the financial system. The introduction of higher capital and liquidity requirements in the aftermath of the global financial crisis have made individual financial institutions more resilient. More potential tail events are now covered. At the same time, this means that a larger number of future crises will be caused by events further in the tail.

The purpose of this paper is to provide an overview of methods for the identification, assessment and mitigation of tail risks and uncertainties. The basic input for the paper is obtained from interviews with 20 experts working at financial institutions and in other sectors with considerable exposure to tail risks and uncertainties. The two central concepts in this paper are tail risks and uncertainties. The following definition clarifies the difference between the two: events that have a strong negative impact on financial institutions and the financial system and whose probability of occurrence is low (tail risk) or unmeasurable (uncertainty).

Tail risks are drawn from a probability distribution with known parameters. This, therefore, is a measurable risk. Uncertainty, by contrast, cannot be measured; the probability distribution and parameters are not known. In practice, this distinction between tail risks and uncertainties is far less clear-cut. Lack of data makes it difficult to estimate a probability distribution for rare events. Interviews with experts confirm that a distinction is hard to make in practice. Insofar as a probability distribution can be determined, it is important to differentiate between tail risks and normal risks. Risk managers often classify events that are more than three standard deviations from the average as a tail risk; however, assuming a normal distribution, this definition is too narrow. Assuming a one-year horizon, it would only take into account events occurring less than once every 700 years. The main reason for this lack of rigour is that the normal probability distribution fails to do justice to practical reality. As personal experience plays an important role in risk perception, tail risk can be defined as an event occurring only once in a 40-year career. This is equivalent to a probability of occurrence (on a one-year horizon) of less than 2.5 per cent.

METHODOLOGY

Tail risks and uncertainties demand an active approach from financial institutions and supervisory agencies. A structured approach breaks down into three phases: identification, assessment and mitigation.[4] The first phase is to identify events with a small probability and a potentially strong negative impact. The second phase is to assess whether these events will indeed have a strong negative impact on a financial institution or the financial system. If this is the case, the third phase is to reduce the probability of the event occurring or to reduce its impact. The three phases jointly constitute an iterative process. This means that financial institutions and supervisory agencies must actively address tail risks and uncertainties in a continuous ongoing process. Each phase is discussed in detail below. As the information here is largely based on the interviews; the examples cited mainly concern the experiences of individual institutions.

Identification

Identification is the first phase in the methodology for actively managing tail risks and uncertainties. This is a crucial phase as tail risks and uncertainties are rare and hard to predict. As a result, they can easily go unnoticed. An added difficulty concerns behavioural biases impeding the identification process.[5]

Identification rests largely on human judgment and is therefore prone to behavioural bias. Four types of behavioural biases are key in disturbing identification.[6,7] First is the *halo effect*, where a specific experience colours an individual's judgment of a broader phenomenon or event. This predisposition can, for instance, cause a risk manager to develop tunnel vision. Related to this is the *affect heuristic*, a mental shortcut enabling people to make decisions quickly and efficiently based strongly on their current emotional state. The general feeling that people have about a subject or event determines their estimation of the related risks. For instance, research shows that people who see lots of advantages in new technology think that the related risks are lower than people who see few advantages. Moreover, the human mind tends to focus strongly on risks whose materialisation can be easily imagined, for example, due to lots of media attention. This is also known as the *availability heuristic*. Finally, people are inclined to look for information that confirms their existing impressions and views. This *confirmation bias* causes them to overlook new risks.

These behavioural biases show the need for a structured approach. Two rigorous approaches for identifying tail risks and uncertainties are a data-driven and an expert-driven approach. The data-driven approach primarily focuses on the past, with historical observations serving as the basis for predicting negative events in the future. The expert-driven approach, by contrast, centres on the forward looking opinion of a specialist. Each approach has its strengths and weaknesses. Data analysis is objective but only describes the past, which is not necessarily indicative of the future. Expert opinions can take more account of the future but, at the same time, are subjective.

In practice, the distinction between the two approaches is less black and white. Data analysis cannot do without the opinion of experts and, vice versa, experts form their opinions partly on the basis of past events.

Figure 1 provides an overview of five different risk identification methods discussed below. The

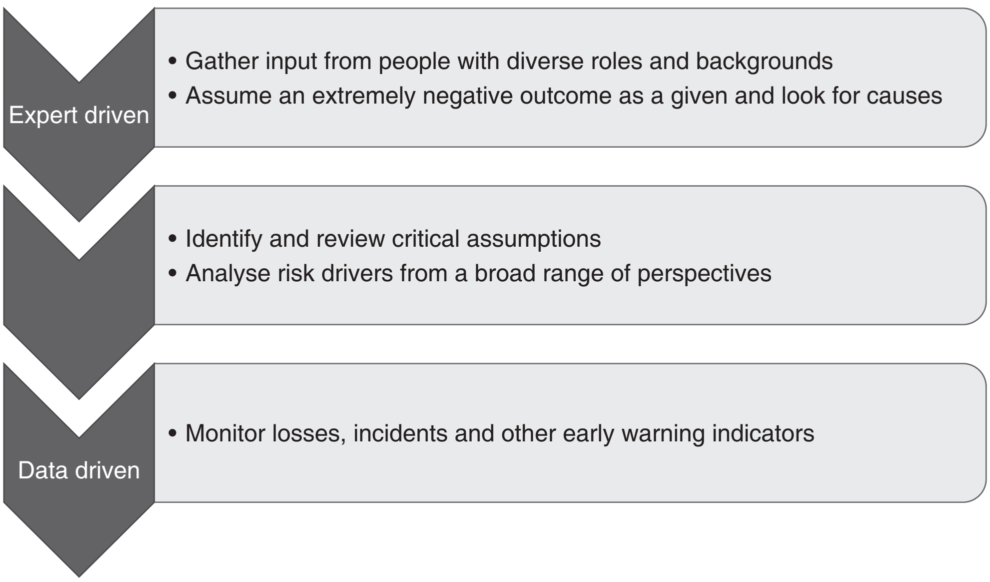

Figure 1: Methods for identifying risks

positioning in the figure indicates whether the method is more expert-driven or more data-driven. It is important to use multiple methods wherever possible in order to increase the probability of identification. Signals that are picked up by only a single method also merit serious attention.

Identification methods for tail risks and uncertainties

Identification method 1: Gather input from people with diverse roles and backgrounds. It is important to gather relevant information on tail risks and uncertainties from as many perspectives as possible. Through listening to *dissenting voices*, more risks are brought to light and the risk of group thinking is reduced.[8] By making connections between different perspectives, threats can be picked up on the radar more effectively. An experiment in the security industry, for instance, shows that a team that includes a hooligan alongside students is the best at detecting threats. It is particularly crucial to prevent group thinking at the start of the identification process. To this end, the design of the initial part of the process should be such that the possibility of participants influencing each other's input is minimised. Participants in a meeting can, for instance, be asked to put their contributions on paper before reading them out one by one. This ensures that the first speakers do not influence the speakers who follow them. An element of competition can also help to gather information from different angles. One large insurer, for instance, holds an annual competition challenging employees to spot and highlight new or strongly increasing risks.

Identification method 2: Assume an extremely negative outcome as a starting point and look for causes. The intention here is to actively guide the imagination and analysis towards events that, for example, threaten the existence of a financial institution. This approach is commonly used in premortem analyses and reverse stress tests. A pre-mortem analysis assumes that a financial institution has run into problems and then tries to trace and work out the possible causes.[9] Making risks more specific helps risk managers in assessing the probability of occurrence. A reverse-stress test involves identifying the scenarios in which the business model is no longer viable and the financial institution will fail.[10] A comparable instrument used in the security and IT world for tracking down the 'unknown unknowns' is the red team exercise. The red team gets the instruction to attack the blue team. This leads to the identification of weak spots in, for instance, the security organisation. Supervisory agencies apply this method to test the cyber-resilience of financial institutions. Here, the red team is given carte blanche to carry out a cyberattack on a financial institution to see whether it can break into the IT system.

Identification method 3: Identify and review critical assumptions. This serves to focus attention on factors that are difficult to estimate. One practical application involves challenging all critical assumptions in risk models. This can be done in both qualitative and quantitative terms. One example of a critical assumption is an interest rate model that excludes the possibility of negative interest rates.[11] Challenging this assumption would have helped financial institutions to assess and prepare for the consequences of negative interest rates at an earlier stage.

Identification method 4: Analyse risk drivers from a broad range of perspectives. Study major structural changes and trends. If such changes and trends occur around or within the financial sector, old patterns and relationships may collapse and new risks can arise. It is thereby crucial to look beyond the obvious risks and risk categories. More and more financial institutions indicate to closely monitor fintech and climate related risks, as developments in these areas have major implications for their business model in the long term.

Identification method 5: Monitor losses, incidents and other early warning indicators. This can help detect a shift in the expected losses within a specific balance sheet item, such as an increase in credit portfolio losses. This could, in turn, prompt a wider investigation to see whether the underlying risk driver might cause further losses elsewhere. It is also useful to monitor indicators which, in the past, have shown a specific pattern in the run-up to financial crises. For instance, a sharp rise in debt financing often signals growing vulnerabilities. Various phases of the financial crisis were also visible in the interbank money market.[12] New technologies offer innovative ways to identify risks. Artificial intelligence and machine learning make it possible to analyse vast quantities of structured and unstructured data in order to detect new risks. Such suptech applications are already being employed for the detection of economic crime and identification of emerging risks.[13] Whereas prudential supervision tends to look back to the past, suptech transforms risk and compliance monitoring into a predictive process.

Assessment

After identification, the tail risks and uncertainties must be assessed. This is the second phase of the methodology. In practice, it consists of making an estimation of the impact and, insofar as possible, the probability of the event.[14] Three methods can be distinguished for this purpose: prioritising, quantitative models and scenario analysis. Prioritising is the first step of the assessment process. Quantitative models are suitable for assessment purposes if sufficient reliable data are available; however, when it comes to tail risks and uncertainties, the data are often either not available or not representative. In such cases, scenario analysis provides a solution. Figure 2 gives an overview of various methods for assessing tail risks and uncertainties.

Assessment methods for tail risks and uncertainties

Assessment method 1: Prioritising. The first assessment step is to prioritise. Each identified potential tail risk and uncertainty is reviewed to see whether it needs further investigation. This assessment is usually based on expert judgement. Prioritising and reducing the number of tail risks and uncertainties is important to allow more in-depth investigation of the risks that are considered to be the most critical. In fact, prioritising often takes place implicitly. It is, however, important to make sure that this step does not result in tail risks and uncertainties being eliminated too quickly based on a perceived low probability.

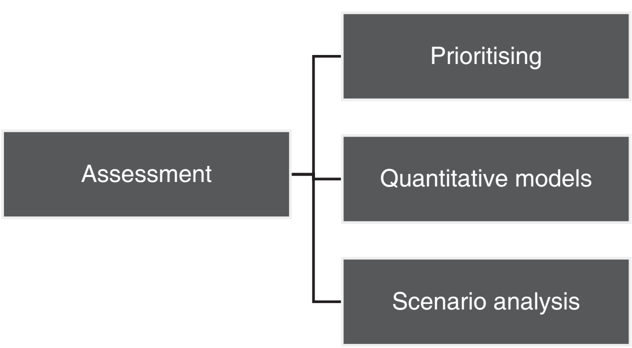

Figure 2: Methods for assessing tail risks and uncertainties

Assessment method 2: Quantitative models. One method for assessing tail risks and uncertainties involves the use of quantitative models. A model is a simplified representation of reality. If enough data are available and it is plausible to assume that no structural changes will take place in the future, a model-based approach is fruitful. The selected distribution of probabilities provides an overview of potential negative events, the accompanying probability and the size of the risk.

Recent literature suggests that power laws help quantifying many fat tailed phenomena in economics and finance.[15] Under a power law the probability of observing variable X to be larger than threshold g is given by

$$P(X > g) = g^{-\zeta}.$$

High-frequency normalised stock returns can be used to find that the exponent ζ is close to 3.[16] This 'cubic rule' is true for both positive and negative tails. Forced selling by large financial institutions in illiquid markets causes markets to crash.[17] Power laws are also applied in modelling natural disasters such as earth quakes, extreme floods, hurricanes, tornadoes and snow avalanches.[18] Using quantitative models for a meaningful assessment requires the following:

- *Large databases.* Quantitative analysis of rare events is particularly difficult and requires extremely large databases or extremely long time periods to reach statistical reliable conclusions.[19] With the exception of financial market data, financial institutions often have a limited quantity of data. For many risk areas, for instance, the data of banks only go back 10 to 15 years. In this case, it is difficult to estimate events occurring less than once every 40 years. When data are limited, such as for operational or business model risks, a fully quantitative approach is less suitable.

- *High data quality.* If the quantity of data is sufficient, the next step is to look at the quality. The quality of the data is assessed along the dimensions of correctness, completeness, representativeness and timeliness. If, for instance, there is a structural change in circumstances, data pre-dating this change may be less relevant for estimating future risks. The use of flu epidemic data is a good example here. As the epidemics occurred before widespread vaccination was introduced, these data are less relevant for estimating the impact of future epidemics in our era of widespread vaccination.
- *Focus on behaviour in the tail of the distribution.* The distribution of extreme observations does not necessarily follow the same pattern as that of non-extreme observations. For this reason, caution is in order when applying a single probability distribution. For this reason, it is necessary to devote explicit attention to the observations in the tail, for instance, by using a different probability distribution for the tail. One option is to use extreme value models.[20] In this case, observations in and around the tail are used to estimate the probability and impact of events that are more extreme than all events that have occurred so far. A large quantity of data is necessary for this purpose as only a small portion of the data is located in and around the tail. In practice, risk managers also use non-normal distributions that do not fall under the extreme value models but do try to catch non-normality as well as possible. Examples are Student *t*-distributions and Weibull distributions.
- *Analyse correlations between variables.* In times of stress, it is particularly essential to study correlations between variables. In crisis periods, correlations between risk categories can diverge strongly from the correlations in normal conditions. Re-insurers investigate whether variables that are generally assumed to be less correlated suddenly display a strong correlation in times of stress.[21] One large financial institution does this, for instance, by organising an annual one-day meeting during which risk managers, quantitative analysts and external experts jointly look at risks and dependencies. Since the global financial crisis financial institutions less routinely use normal distributions in risk management. Many use, for example, copula models for measuring tail risks in investment portfolios.
- *Vary parameters and models.* A model is a simplified representation of reality, which implies that certain effects and relationships are left out of consideration. In addition, the choice to use a certain model is subjective. For this reason, it is important to apply different parameter sets within the same model or use different models. Box 1 reviews several probability distributions for assessing tail risks in the stock market.

BOX 1: MODELLING TAIL RISKS IN THE STOCK MARKET

The following example shows the importance of using different models in assessing tail risks. The example analyses daily returns on the S&P500 index over the period January 1950 through September 2018, or 17,292 observations. The standard deviation of the daily returns is approximately 1 per cent. It is known that the distribution of stock returns has fat tails. On 19th October, 1987, for example, the stock market index dropped more than 20 per cent. Under a normal distribution that would be a '20 sigma' event. The sample also contains three 9 sigma and two 8 sigma events. Cleary these events are virtually impossible under a normal distribution. It is therefore worthwhile to explore the following distributions that may offer a better fit to the fat tails in the data: an Extreme Value, a Weibull and a Student-*t* distribution. The empirical fit to the returns data is then used to numerically derive the tail value at risk (TVaR) for several probabilities, ranging from 2.5 to 0.005 per cent. TVaR measures the expected loss over all scenarios that have a loss greater than the value at risk for a given probability, or formally $TVaR = E[R \mid R < VaR_{\alpha}]$. TVaR is very similar to loss given default or tail conditional expectation. Table 1 and Figure 3 show the results of our empirical analysis.

Table 1: Tail value at risk for different distributions and probability levels

Probability	0.025	0.01	0.001	0.0001	0.00005
Normal	–0.022	–0.025	–0.032	–0.038	–0.039
Extreme value	–0.045	–0.050	–0.060	–0.066	–0.068
Weibull	–0.051	–0.060	–0.081	–0.098	–0.103
Student-*t*	–0.029	–0.040	–0.086	–0.180	–0.225

Under the normal distribution the stock market return on a given day will be less than –1.8 per cent with a probability of 2.5 per cent. This is the value at risk measure. The TVaR or the expected loss over all scenarios that lead to a greater loss is –2.2 per cent under the normal distribution (row 2, column 2). The equivalent TVaR for the extreme value and the Weibull distribution are –4.5 and –5.1 per cent. Going from the left to the right in Table 1 shows that the TVaR gets larger and larger. This is logical, as the expected loss is evaluated deeper down in the tail. The same dynamics is observed in Figure 3, where the TVaR becomes more negative as the probability decreases. This effect is strongest for the Student-*t* distribution as the losses for that distribution are much larger for small probabilities than for the other distributions. The Student-*t* distribution performs the best in the tails of daily stock returns from 1950 to 2018. The TVaR for a probability of 0.01 per cent is an expected daily loss of 18.0 per cent (row 5, column 5), which comes closest to the probability and loss of the stock market crash in October 1987. Quantitative analysis of the statistical properties of rare, but not improbable, events is difficult and requires very large datasets or very long time periods to derive reliable conclusions. The analysis above can be done because it relies on satisfactory data. Obviously these data are less available for many other risk factors.

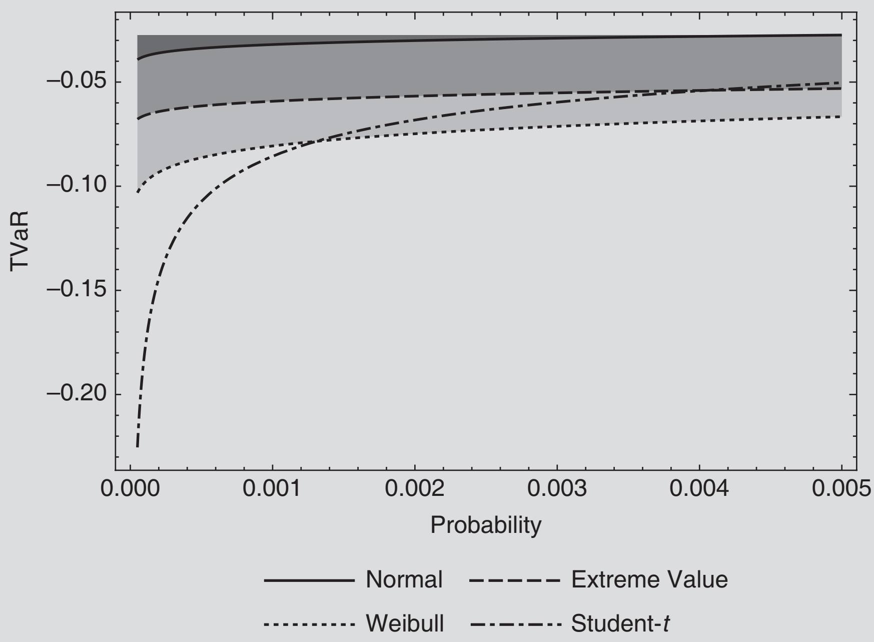

Figure 3: Tail value at risk for different distributions and probability levels

Assessment method 3: Scenario analysis. This is another method for assessing tail risks and uncertainties. Scenario analysis is an important instrument when the quantity or quality of data is insufficient. The main purpose of scenario analysis is to estimate the impact — rather than the probability — of a risk event. A scenario is a specific realisation of an uncertain future.

Scenario analysis and quantitative models can also be used in combination in, for instance, a stress test.[22] Once a negative qualitative scenario has been determined, a quantitative model can be used to estimate the impact for the financial system or for individual financial institutions. Since the global financial crisis, the use of scenarios and their application in stress tests has greatly increased. Many institutions perform their own stress tests in addition to the supervisory stress tests.

The following requirements are pivotal for performing a proper scenario analysis:

- *Ensure that scenarios are plausible.* A scenario must be plausible; analysis of scenarios that cannot possibly occur in practice has no added value. A plausible analysis is only possible if the scenario is based on valid qualitative assumptions. Clear and sound assumptions also make it easier for an institution to recognise a scenario if it actually unfolds in practice. Certain methods from the identification phase, such as analysis of potential risk drivers and pre-mortems, are also useful for the formulation of qualitative assumptions.
- *Ensure that scenarios are extreme.* A scenario must be extreme to minimise the risk of underestimating the potential impact of events. To ensure that an analysis is sufficiently extreme, it is important that risk managers are free to draw up scenarios independently and without restrictions.
- *Involve people with diverse roles and backgrounds in the scenario formulation process.* Involving people with diverse roles and backgrounds contributes to scenarios that are both plausible and extreme. It reduces the risk of a one-sided fixation on desired outcomes (single outcome bias) and the danger that only known risks are taken on board while overlooking unknown risks (ambiguity bias).
- *Also look at the qualitative impact.* Apart from a quantitative analysis, it is also important to make a qualitative analysis. This qualitative analysis can, for instance, provide insight into the exact ways in which scenarios have an impact on the institution. This increases the possibility of timely mitigation measures. It is important to analyse not only first-order but also second-order effects of the scenario.

One general recommendation is to use multiple methods wherever possible to assess tail risks and uncertainties. These diverse methods will not necessarily lead to the same outcomes in terms of probability and impact. Every choice of model or scenario is inherently subjective. Modelling concerns a continuous, iterative process. Models are ideally tested continuously for realism (eg, through out-of-sample backtests), and continuously adapted and improved to make the models better. Moreover, a model or scenario only captures a part of reality. That is why it is vital to use diverse methods in order to make the most comprehensive assessment possible of potential risks and uncertainties. Even if sufficient, good quality data are available, a scenario analysis can still lead to different insights from a quantitative model. This recommendation is particularly relevant in an environment where there is a firm belief in the accuracy of risk models. If the inherent uncertainty of model outcomes is not recognised, the shock can be all the greater when reality turns out to be a lot less predictable than the model implied.

Mitigation

The final step, after the identification and assessment of tail risks and uncertainties, is mitigation. This is the third phase of the methodology. Mitigation is, first of all, the responsibility of the senior management of financial institutions. But supervisory agencies and central banks also play a crucial role as they supervise the compliance of the risk management of financial institutions, assess recovery and resolution plans, and take measures at the systemic level.

Before discussing mitigation methods in more detail, a few general observations are important to make. Even good identification and assessment methods cannot ensure that all tail risks and uncertainties are noticed (in time). The future, after all, is highly uncertain. Mitigation strategies of financial institutions, supervisory agencies and policymakers must take this fundamental uncertainty into account.[23] From a supervisory and policymaking perspective, this can be done, for instance, by limiting the impact of individual bank failures. This is worked out in more detail below under mitigation method 3.

At the same time, not every tail risk and uncertainty always requires immediate mitigation. It depends on whether the risk falls within the institution's risk tolerance. If the probability multiplied by impact — that is, the risk — is however greater than the institution's risk tolerance, mitigation is required. Even if the probability is unknown, but materialisation is considered plausible and the impact could be disastrous, control measures are necessary, particularly if these are relatively easy to implement.

Sometimes, early warning signals make it possible to pre-empt the event with timely mitigation actions. In such cases, mitigation can take place on the basis of an escalation ladder. If the event has been identified, but cannot materialise in the foreseeable future, limited contingency planning may be sufficient in the first instance. In this case, however, the organisation must clearly indicate the conditions under which additional mitigation actions should be taken. To this end, threshold values can be set for measurable variables to trigger additional mitigation actions when the risk becomes more imminent.

In practice, of course, mitigation steps are sometimes taken too late. One well-known cause is the information bias.[25,26] As estimates of tail risks and uncertainties are often incomplete and imperfect, organisations can fall into the trap of looking too long for additional information and thus failing to take mitigating actions in time. The most common risk mitigation measures are discussed below. A distinction is made between methods used by financial institutions and methods that supervisory agencies have at their disposal.

Mitigation methods for tail risks and uncertainties: Financial institutions

Three methods for reducing tail risks and uncertainties are: control measures, capital buffers and institutional measures.[27] Figure 4 plots the different methods.

Mitigation method 1: Control measures. Financial institutions can take control measures to reduce the probability of the risk materialising and its impact. To be effective, risk management must be an integral part of the institution's governance and culture. The institution's culture should encourage staff to identify, discuss and address tail risks and uncertainties. Financial institutions can deploy the following control measures:

- *Risk reduction.* An institution can mitigate risks by limiting the size of the exposure. The most far-reaching measure is to entirely avoid certain exposures. Apart from size, time is also a key factor in the risk reduction process. For instance, an institution can limit its exposure by keeping the term of its contractual obligations short. There are, however, limits to risk reduction strategies: tail risks and uncertainties can never be entirely eliminated.
- *Risk diversification.* If a tail risk or uncertainty affects a specific part of the assets or liabilities, an institution can mitigate this risk by diversifying its exposures. Diversification across sectors and geographical areas, for instance, limits the overall risk profile of the financial institution. But there are also limits to diversification. If, for instance, the tail risks and uncertainties affect a larger portion of the assets and liabilities than originally thought, diversification may be less effective than anticipated. Moreover, new risks can arise at the systemic level if a large number of financial institutions all opt to diversify their risks in an identical manner (see Box 2).[28]
- *Risk transfer.* The risk can be externally hedged by means of, for instance, a swap or re-insurance; however, not all risks can be hedged in this way. The failure of a re-insurer is, in itself, a tail risk or uncertainty. In addition, inadequate and/or speculative use of derivatives positions can actually lead to extreme exposure to certain tail risks and uncertainties.
- *Contingency planning.* Contingency planning is a way of addressing risks internally. Precautionary measures are particularly relevant for tail risks and uncertainties as it is usually unclear when and in what form an event will take place. Here are two examples of contingency planning: protection of ICT systems and trading strategies. Regarding ICT risks (including cyberattacks), it is important to train employees, hold regular drills and install a back-up IT system (business continuity management). In the specific case of cyberattacks, full prevention of infiltration is impossible. The focus, therefore, must be on ensuring that infiltration cannot occur unnoticed and on minimising the possibility to damage or compromise the ICT system (impact reduction). Asset managers offer dynamic trading strategies where the risk profile of a portfolio is reduced as soon as certain triggers are activated; however, dynamic trading strategies can in themselves

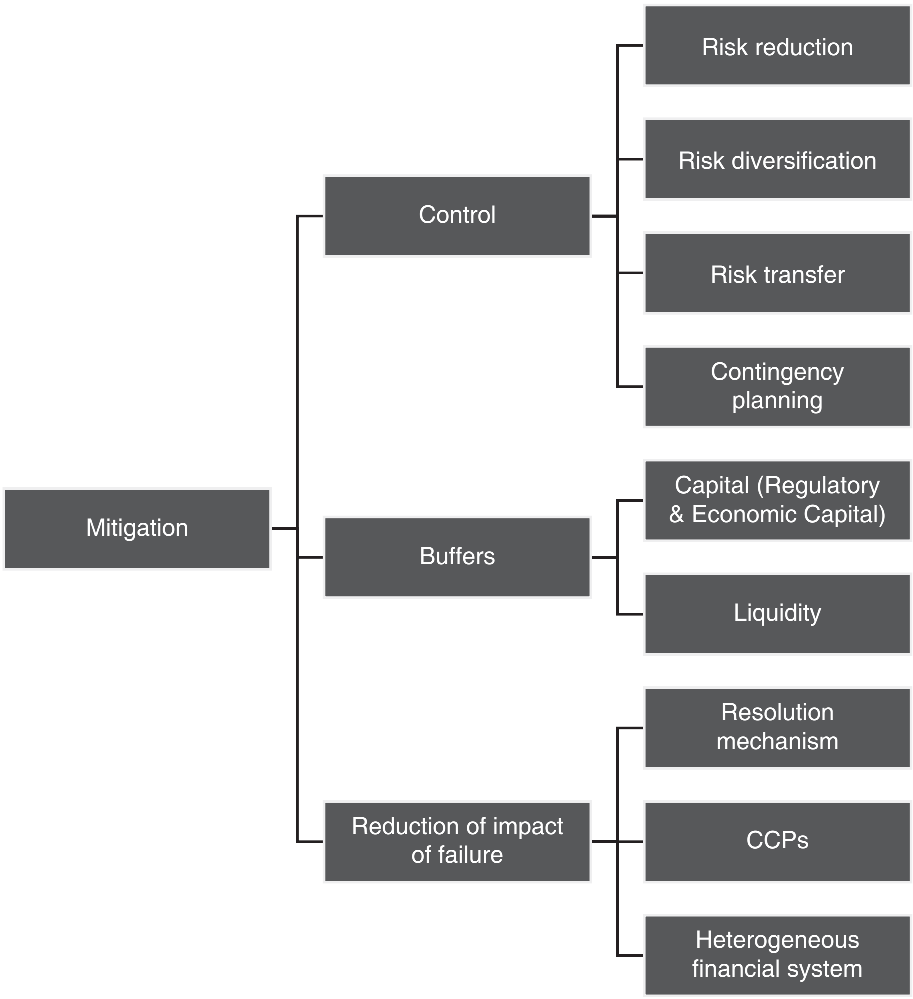

Figure 4: Impact of mitigation of tail risks and uncertainties at financial institutions
Note: CCP, central counterparties

create a self-reinforcing negative spiral and cause liquidity to dry up in times of stress.[29]

Mitigation method 2: Adequate capital and liquidity buffers. This method mitigates the impact of tail risks and uncertainties. Capital rules prescribe minimum equity requirements for institutions. The minimum required capital is set at a level to ensure that the risk that an institution cannot meet its obligations is reduced to a specific percentage. Since the global financial crisis, the capital requirements for financial institutions have been increased, both in terms of size and quality. After the crisis, regulations were also brought in to reinforce liquidity buffers.

Mitigation method 3: Institutional measures to reduce the impact of the failure of individual institutions. From the perspective of the financial system, the impact of tail risks and uncertainties is mitigated by reducing the losses resulting from the failure of individual financial institutions. Resolution mechanisms for banks (single resolution mechanism (SRM)) and insurers and the central derivatives clearance process via central counterparties (CCPs) have been specifically set up for this purpose. Note, however, that a CCP that runs into problems can in itself be a tail risk for member banks and the system. Heterogeneity can also contribute to the resilience of the financial system. If financial institutions are less homogeneous,

BOX 2: FALLACY OF COMPOSITION

Safe individual institutions do not automatically imply that the financial system as a whole is also safe.[30] There is a fallacy of composition. If financial institutions are homogenous it will increase the joint default probability and negatively impact the stability of the financial system as a whole. To formalise the argument consider two banks, A and B. The default for each bank is given by a Bernoulli distribution with probability p. The join default probability measures the probability of a systemic crisis and is given by p_{AB}. The correlation coefficient between a default of the two banks is given by

$$\rho_{AB} = \frac{E[\mathbf{1}_{\{A\}}\mathbf{1}_{\{B\}}] - E[\mathbf{1}_{\{A\}}]E[\mathbf{1}_{\{B\}}]}{\sigma_{\mathbf{1}_{\{A\}}}\sigma_{\mathbf{1}_{\{B\}}}}$$

where $E[\mathbf{1}_{\{A\}}] = p, \sigma_{\mathbf{1}_{\{A\}}} = \sqrt{(1-p)p}$ and $\mathbf{1}_{\{A\}} = \begin{cases} 1 \text{ if bank A defaults} \\ 0 \text{ otherwise} \end{cases}$. The definitions are equivalent for bank B. Assuming that the default probability for the individual banks is identical it follows that the joint default probability is equal to

$$p_{AB} = p^2 + \rho_{AB}p(1-p)\,.$$

This formula delivers some key insights on systemic risk. If two uncorrelated banks each have a default probability of 1 per cent, the joint default probability is only 0.01 per cent; however, if the banks are perfectly correlated, the joint default probability jumps to 1 per cent. The probability of a systemic tail event is now hundred times bigger compared to a world with uncorrelated banks. Only looking at default probabilities of individual banks would create a blind spot in the identification of extreme events.

there is less risk of simultaneous failure which, in turn, reduces the risk of a systemic crisis.

Mitigation of tail risks and uncertainties: Supervisory agencies

Next to the toolbox of financial institutions, supervisory agencies have several mitigating instruments at their disposal.[30] Some are designed to ensure that financial institutions implement the mitigation methods described above. Others are aimed at other stakeholders, such as the legislator and regulatory bodies. Four groups of instruments are distinguished below: signalling, supervisory instruments, additional instruments (eg, macroprudential and resolution instruments), and policy influencing and development. Each method is briefly explained.

Mitigation instrument 1: Signalling. Supervisory agencies make financial institutions aware of tail risks and uncertainties in various ways. The underlying aim is to encourage them to take mitigating measures. Typical awareness-raising instruments include publications, interviews in the media, speeches and the organisation of meetings, for example, roundtable meetings.

Mitigation instrument 2: Supervisory instruments. Supervisors verify whether financial institutions sufficiently mitigate risks based on day-to-day and on-site supervision. Supervision of contingency and recovery planning is particularly vital for the mitigation of tail risks and uncertainties. Supervision of business conduct and culture is also important. Awareness of tail risks and uncertainties is an important indicator of a director's suitability to carry risk management responsibility. If financial institutions fail to take the desired measures, operational supervision can mobilise various instruments to persuade institutions to take appropriate action such as supervisory meetings, directives, penalties or an adjustment of the institution-specific capital requirement.

Mitigation instrument 3: Additional instruments such as macroprudential and resolution instruments. The use of macroprudential instruments such as capital and counter-cyclical buffers contribute towards mitigation. The risk of extreme events may imply making buffers extra conservative or maintaining a straightforward non-risk-based buffer. The same applies to resolution plans for reducing the impact of institutional failures. These are drawn up by the banks on instructions of the supervisory agency.

Mitigation instrument 4: Policy influencing and development. If the above instruments prove inadequate to mitigate tail risks and uncertainties, a solution may be found in adjusting policies or developing new policies. This concerns, for instance, adjustments to prudential frameworks for financial institutions, macroprudential policy and resolution policies.

CONCLUSION

Tail risks and uncertainties are rare events that have a strong negative impact on financial institutions and the financial system, while their probability of occurrence is low (tail risk) or unmeasurable (uncertain). The financial system is inherently vulnerable to tail risks and uncertainties. Both financial institutions and supervisory agencies must actively seek to reduce the probability and impact of tail risks and uncertainties. This active attitude can benefit from a structured methodology. The three chief components of that methodology are identification, assessment and mitigation.

Clearly, the structured methodology as set out in this paper is not in itself sufficient to consign tail risks and uncertainties to the past. But it does ensure that financial institutions and supervisory agencies are better prepared for a scenario in which a tail risk event or uncertainty actually materialises. This contributes towards greater risk awareness and a more stable financial system. This paper offers financial institutions and supervisory agencies concrete suggestions for developing an active and structured approach to tail risk and uncertainty management as an integral part of their risk management procedures.

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References and notes

1 Taleb, N. N. (2007) 'The black swan: The impact of the highly improbable', Random House, New York.

2 The capital requirement calculation for financial institutions assumes a maximum default probability on a one-year horizon of 0.1 per cent for banks under Basel III and 0.5 per cent for insurers under Solvency II. For Dutch pension funds, capital requirements are such that the probability of the funding ratio falling below 100 per cent on a one year horizon is 2.5 per cent.

3 On 13th August, 2007, Goldman Sachs announced that two hedge funds had lost 25 per cent of their value due to three successive days of losses in financial markets that were 25 standard deviation moves from the average. In most models, the probability of a single such event happening is negligible, let alone three in a row.

4 Hopkin, P. (2018) 'Fundamentals of risk management', 5th edition, KoganPage, New York.

5 Tversky, A. and Kahneman, D. (1974) 'Judgment under uncertainty: Heuristics and biases', *Science*, Vol. 185, No. 4157, pp. 1124—1131.

6 Kahneman, D. (2011) 'Thinking, fast and slow', Farrar, Straus and Giroux, New York.

7 Jansen, R. and Aelen, M. (2015) 'Biases in supervision: What are they and how can we deal with them?', *DNB Occasional Studies*, Vol. 13, No. 6, pp. 1–35.

8 Braithwaite, V. (2017) 'Closing the gap between regulation and the community', in P. Drahos (ed.) Regulatory theory: Foundations and applications, ANU Press, Acton, pp. 25–42.

9 Klein, G. (2008) 'Performing a project premortem', *Engineering Management Review*, Vol. 36, pp. 103–104.

10 BIS (2009) 'Principles for sound stress testing practices and supervision', Consultative Document, Bank for International Settlements, available at: https://www.bis.org/publ/bcbs155.htm (accessed 4th November, 2018).

11 Cox, J. C., Ingersoll, J. E. and Ross, S. A. (1985) 'A theory of the term structure of interest rates', *Econometrica*, Vol. 53, No. 2, pp. 385–407.
12 Timmermans, M., Heijmans, R. and Daniels, H. (2017) 'Cyclical patterns in risk indicators based on financial market infrastructure transaction data', *DNB Working Paper*, No. 558.
13 Broeders, D. W. G. A. and Prenio, J. (2018) 'Innovative technology in financial supervision (suptech) — the experience of early users', *FSI Insights*, No. 9, pp. 1–26.
14 In this phase, too, behavioural biases may distort the process. It is known, for instance, that when people have identified events that are extremely unlikely to materialise, they tend to attach disproportionate value to the realisation of a positive outcome (winning a lottery) or the avoidance of a negative outcome (avoiding a loss). This implies that it is also possible to attach too much significance to tail risks. But on the whole, this does not apply to the financial sector which, given its critical social role and the ever-present risk of contagion and other systemic effects, should devote sufficient attention to all risks, including those with a low probability of occurrence.
15 Gabaix, X. (2016) 'Power laws in economics: An introduction', *Journal of Economic Perspectives*, Vol. 30, No. 1, pp. 185–206.
16 Gopikrishnan, P., Meyer, M., Amaral, L. A. N. and Eugene Stanley, H. (1998) 'Inverse cubic law for the distribution of stock price variations', *European Physical Journal*, Vol. 3, No. 2, pp. 139–140.
17 Gabaix, X., Gopikrishnan, P., Plerou, V. and Eugene Stanley, H. (2003) 'A theory of power-law distributions in financial market fluctuations', *Nature*, Vol. 423, No. 6937, pp. 267–270.
18 Sanders, D. E. A. (2005) 'The modelling of extreme events', *British Actuarial Journal*, Vol. 11, No. 3, pp. 519–557.
19 Mantegna, R. N. and Eugene Stanley, H. (1999) 'An introduction to econophysics: Correlations and complexity in finance', Cambridge University Press, Cambridge.
20 Gilli, M. and Këllezi, E. (2006) 'An application of extreme value theory for measuring financial risk', *Computational Economics*, Vol. 27, No. 1, pp. 1–23.
21 Zheng, Z., Podobnik, B., Feng, L. and Li, B. (2012) 'Changes in cross-correlations as an indicator for systemic risk', *Scientific Reports*, 2, Article No. 888, pp. 1–8.
22 BIS (2017) 'Stress testing principles', Consultative Document, Bank for International Settlements, available at: https://www.bis.org/bcbs/publ/d428.htm (accessed 4th November, 2018).
23 Cardano (2017) 'Memento futuri: Op zoek naar stabiliteit in een onzekere wereld', available at: https://portal.cardano-imagine.nl/whitepaper-memento-futuri (accessed 4th November, 2018).
24 To mention one example, a scenario analysis by a Dutch financial institution revealed a large mismatch between its assets and liabilities in a European country. Severe eurozone instability could lead to significant losses. Although the probability of this scenario was difficult to estimate, the institution decided for reasons of prudence to take mitigation measures.
25 Douglass, H. (2017) '10 cognitive biases that can lead to investment mistakes', Cuffelinks, available at: https://www.magellangroup.com.au/insights/10-cognitive-biases-that-can-lead-to-investment-mistakes/ (accessed 4th November, 2018).
26 Rossi, C. (2017) 'How behavioral economics can elevate strategic risk management', CRO-outlook, available at: https://www.dnb.nl/en/news/news-and-archive/DNBulletin2018/dnb376252.jsp (last accessed: 4 November 2018).
27 Merton, R. C. and Bodie, Z. (1992) 'On the management of financial guarantees', *Financial Management*, Vol. 21, No. 4, pp. 87–109.
28 Beale, N., Rand, D. G., Battey, H., Croxson, K., May, R. M. and Nowak, M. A. (2011) 'Individual versus systemic risk and the regulator's dilemma', *PNAS*, Vol. 108, No. 31, pp. 12647–12652.
29 The stock exchange crash of 1987 is often attributed to the automated sell-off strategies of options traders that were activated when share prices dropped to a certain level.
30 DNB (2018), 'Proportional and effective supervision,' *De Nederlandsche Bank*, available at: https://www.dnb.nl/en/news/news-and-archive/DNBulletin2018/dnb376252.jsp (accessed 4th November, 2018).