

Stochastic modelling of liability accumulation risk



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Contents

| | |
|--|----|
| Executive summary..... | 5 |
| 1. Introduction | 8 |
| 2. Concepts | 9 |
| 2.1 Selected scenarios analysis | 9 |
| 2.2. Economic parameters | 11 |
| 2.3 Trade maps | 11 |
| 3. Process | 12 |
| 3.1 Expert interviews | 12 |
| 3.2 Historical data..... | 12 |
| 3.3 Relevant industries..... | 13 |
| 4. Shapes | 14 |
| 4.1 Corporate shape..... | 16 |
| 4.2. Infrastructure/operational shape | 19 |
| 4.3 Product/service shapes | 21 |
| 4.3.1 Component/ingredient shape | 22 |
| 4.3.2 Finished product/service shape..... | 25 |
| 4.4 The “professional claw” | 29 |
| 5. Use of parameterised shapes to generate future scenarios..... | 30 |
| 5.1 Food-related scenarios..... | 30 |
| 5.2 Emerging risk: sugar | 30 |
| 6. Outputs | 32 |
| 6.1 Exceedance probability curves | 32 |
| 6.2 Heat maps and clusters..... | 32 |
| 7. Conclusions | 33 |
| 8. Appendix | 34 |
| 8.1 Scenarios used..... | 34 |
| 8.2 Experts’ observations | 35 |
| 8.3 Occurrence probabilities..... | 41 |
| 8.4 Technical implementation of the concept..... | 41 |
| References..... | 44 |

Executive summary

Background

Casualty risks accumulate in a variety of different ways and affect many lines of business. This makes it challenging for insurers to approach casualty risk accumulation systematically.

This new Lloyd's report, published in partnership with Arium, addresses this challenge by using a new stochastic approach to modelling liability exposure. This innovative methodology, designed by Arium and Lloyd's, can be used for all classes of business in any given portfolio, and allows for a systematic assessment of risk accumulation.

By mapping the economic relationships that reflect the journey of products and services through the economy, the methodology creates liability "storm tracks" that provide a new, structured way of analysing casualty events, regardless of risk classification.

A systematic approach to modelling liability risk

The report shows how this approach can be used to map loss scenarios, and finds that certain economic relationships form patterns consistent with specific types of loss scenarios. The model uses these patterns to create building blocks, called "shapes".

Shapes provide a way of categorising casualty events based on a company's business activities, such as products and services, operations and infrastructure, all of which may be affected by a casualty event. This data is then augmented with loss characteristics of the liability risks connected with these activities in order to create a stochastic model.

Importantly, the report finds that many different scenarios can be modelled using a handful of shape types, where each type can be characterised according to the parameters of the loss event. Breaking liability risk modelling down into blocks, which mirrors the way in which natural catastrophe risks are divided into region-perils, makes it easier to carry out the modelling.

For example, companies affected by fraud or misleading accounting practices are often the hub of a network of professional advisers, bankers and competitors, all whom could be pulled into litigation at varying levels by affected stakeholders. The shapes for such events (of which Enron and WorldCom are examples) look like Figure 1 and Figure 2, respectively, and show the bankrupt company in the centre and its service providers as nodes around the hub. The arrows show the direction and relative strength of trade.

Figure 1: Company implosions, Enron

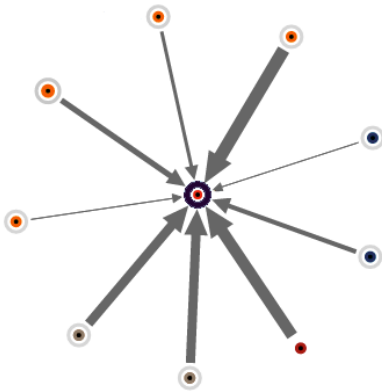
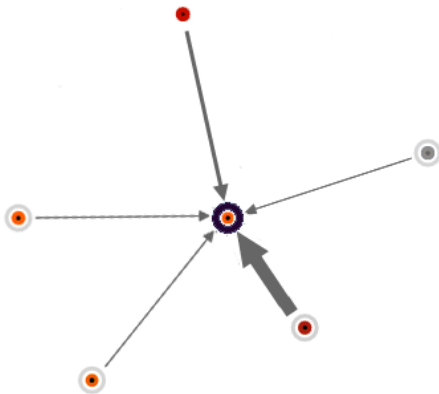
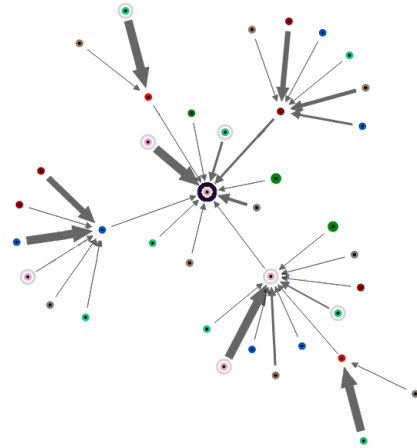


Figure 2: Company implosion, Worldcom



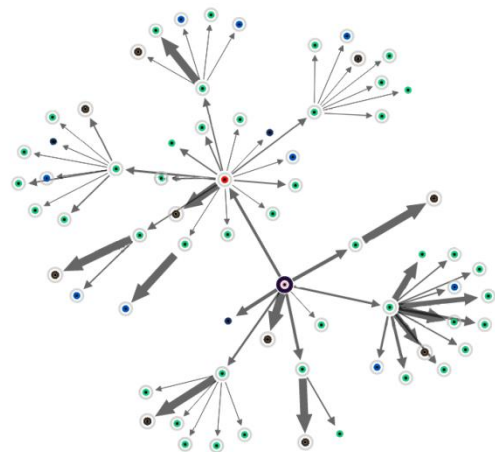
The shapes for infrastructure accidents and explosions, such as Deepwater Horizon, where the owner or the operator of the infrastructure and a number of its contractors and suppliers may be implicated, are different, as Figure 3 shows:

Figure 3: Infrastructure, oil and gas explosion



Events that involve product liability, such as asbestos, are different still, as Figure 4 shows. In such cases the faulty component or ingredient can be contained in many different products, industries and distributors, and has the potential to create losses that increase with the number of parties implicated.

Figure 4: Component, recent major asbestos losses



All the examples above demonstrate the variety of scenarios that can be analysed and modelled using the shapes approach.

Benefits of the new approach

These shapes can be used not only to describe what has happened but also what could happen. Different infrastructure loss scenarios may have different loss sizes but the economic relationships in the supply chains and the key parameters driving the loss will be similar.

One of the key benefits of this new approach is that it can identify hidden risks that have not yet materialised but could do so in the future. The approach generates thousands of potential casualty events, similar to the way in which thousands of synthetic wind-storm tracks are created in natural catastrophe models to describe accumulation exposures in insurers' property portfolios.

This allows insurers to assess liability risk in the way they do when modelling property catastrophe – i.e. using annual average losses, exceedance probability curves and heat maps that allow a visual identification of risk clusters.

The model described in this report is an innovative way of representing casualty accumulations on a probabilistic basis and represents a big step forward in the understanding of liability risk exposure. Going forward, it is vital that risks are coded in a standard way (such as the six digit NAICS codes) to enable the model to reach its full potential.

Next steps

Further research would be useful in the following areas:

- Extending the shapes to capture additional aspects of risk.
- The frequency with which the catalogue of shapes should be refined, adapted or left unchanged.
- Study of the sets of parameters best suited to model a particular shape, as well as refining the probabilities each is associated with.
- Analysis of liability by geographic spread (subject to the availability of further information on US casualty events).

1. Introduction

The basic ideas underlying this paper flow from the report “Emerging Liability Risks - Designing liability scenarios” written jointly by Arium and Lloyd’s in 2015 (Lloyd’s, 2015). Its message was that a suitable framework for modelling liability risks is given by the notion of supply chains, which may be seen as the storm tracks, and by the faultlines of liability risks – their footprint. On this basis, a methodological framework for deriving insured losses from given risk scenarios was discussed.

Adding a stochastic extension of the methodology seemed a natural next step. In simplistic terms, stochastic models applied in insurance are normally a large set of risk scenarios, each associated with a certain probability of occurrence. The goal of this paper is to discuss a way to generate scenarios in large numbers and thus create a stochastic approach to liability risk management. It pivots on the concept of “shapes”, which are classifications of liability risk capturing its mechanics in terms of supply chain as well as economic factors. The mechanics determines the classification and is the key to generating scenarios. In particular, examining a multitude of liability scenarios along the lines of the supply chain methodology pointed to many common features for certain liability risks. These risks could be then bundled together in a way that their commonalities would be preserved, while finding stochastic or deterministic ways to account for the differences that still persisted.

In this sense, shapes are comparable to “region-perils” in the natural catastrophe modelling sphere, although the latter appear less ambiguous, at least at a high level. Liability modelling, by contrast, has traditionally lacked an equivalent concept.

Shapes are a collection of:

- Rules on how to locate the supply chain that underlies the risk scenario (its footprint)
- Rules on how to determine its size and spread, and how systemic it is using insurance-relevant parameters

By using the footprints of historical and emerging scenarios, input from experts and historical data, it became clear that only a handful of shapes were necessary to provide the potential spread and losses associated with different liability scenarios, whether past, present or future. These shapes cut across different liability lines of businesses, different industries, different types of loss and different jurisdictions. The losses and parameters for those shapes were either suggested directly by experts or suggested by historical data, using expert input to help consider how future losses may differ from the past. The input obtained from experts was surprisingly consistent and supported by the historical data when available. The events modelled to date fell into corporate, infrastructure/operational, product component/ingredient, finished product/service shapes plus a professional/financial services shape that can adhere to almost any node in the shapes (see *Section 4, p14*) for a detailed description of shapes’ characteristics.

Unless specifically referenced, historical data and information on particular historical scenarios is sourced, with permission, from Advisen.

2. Concepts

Box 1: Approach concepts

Shape: a model of a supply chain elements and economic parameters associated with a certain type of liability event.

Parameter: a characteristic that defines part of the shape.

Footprint: the supply and distribution chain of parties implicated in a particular liability event. This is generated through the mechanisms prescribed in the shape.

Trade maps: universe of supply and distribution relationships (at an industry level) in an economy.

Systemic events: systemic event as it is used in this paper involves a footprint with a large number of implicated parties in some (or all) industries and also can involve a large number of industries.

2.1 Selected scenarios analysis

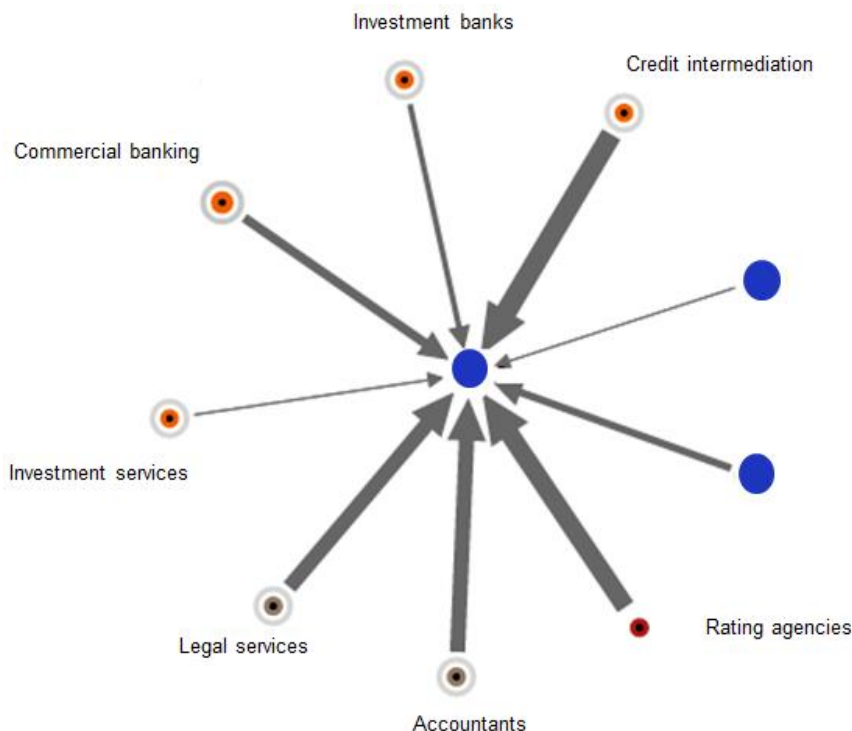
The starting point of the methodology is also the most visual aspect of determining the footprint. A footprint is a map of the supply and distribution chain implicated in a certain scenario. This is generated through the mechanisms prescribed in the shape. Shapes of scenarios mentioned by experts and modelled historical scenarios were discussed and studied, and recurrent patterns were noticed. The underlying labelling of industries follows the NAICS (North American Industry Classification System) because it is a granular classification system and it is used by Federal statistical agencies to classify businesses and provide statistics related to the U.S. economy. The NAICS is also currently used in the Lloyd's Cyber Core Data Requirements (Lloyd's, 2017) and the classification system is kept up to date.

As mentioned in the 2015 Emerging Liability Risks report: "...analysis is only good as the data on which it is based". Indeed there are challenges around the current state of data quality in the insurance industry, but with the insured and insurers' data currently available along with augmenting and standardising techniques, insurers already have a starting point to analyse their liability portfolio and then produce a more accurate and comprehensive dataset.

Consider a shape that reflects the financial implosion of a large corporate as a result of an accounting fraud.

The graphical representation of industries with implicated parties is illustrated in Figure 5.

Figure 5: Company implosion shape example



In this chart there are two kinds of nodes:

- The labelled nodes represent actual industries, which are frequently caught-up in liability scenarios. Examples are commercial banks, accountants, lawyers and financial advisers.
- The anonymous nodes (blue) are placeholders for affected industries in a specific scenario. For this type, large corporates in virtually any industry could be caught up. Although certain factors such as a company having a lot of assets off balance sheet, experiencing recent changes in business practices or rapid growth may result in companies being more vulnerable to an implosion. As a next step, anonymous nodes were replaced by actual industries to obtain scenarios. Compatible historical scenarios were found, inter alia, in telecoms, stock brokers and energy companies.

The parameters associated with a shape capture constants and variables in the supply chain associated with the type of liability event. In practice, this is expressed in the model in one of the following three forms:

- Certain industries are almost always included in the footprint. This makes sense for the type of financial implosion scenario discussed above. Similarly, retailers are often implicated in food contamination

scenarios, while pharmaceutical and medical-related risks often involve wholesalers.

- Particular industries are included only if a certain starting industry is selected. In a food contamination scenario, the type of food determines the supply chain.
- Some industries are usually excluded. For example, banks supplying finance and real estate relating to the premises are usually not implicated in food contamination scenarios.

Under these constraints, scenario footprints are then generated after the inclusion of economic parameters.

2.2. Economic parameters

Once a footprint is generated, economic parameters are added to complete the scenario generation process. These parameters essentially capture the severity and spread of a scenario as well as the concentration of losses in different industries. The most important examples are:

- Size of loss
- Distribution of liability between industries (e.g. in which industries are parties likely to pay most of the losses).
- Number of companies implicated in each industry.
- Period of time over which losses materialise.
- Relevant jurisdictions.

Depending on the shape, these quantities are either captured deterministically or by stochastic mechanism, often through probability distributionsⁱ.

2.3 Trade maps

Trade data helps identify the relevant suppliers and distributors of products and services. This creates the set of potential supply chain relationships implicated in a certain type of liability event (see *Section 4.3, p21* on relevant industries on how this set of possible trade relationships is constrained to the realistic trades for set of scenarios). Trade relationships can also reveal the main suppliers of a given industry. Indeed, the total trade between two industries can be seen as a measure of how economically important one industry is to the other.

To generate a large number of random credible scenarios, the shapes are “moved around” the trade map, so that each synthetic scenario has a starting point and spreads as per the shape and parameters mentioned above, constrained by the relevant trade data. The constraint in the underlying data is that it is necessary to have a trade from the starting industry to another industry and from that industry to another, for any industry to be included in the scenario. For example, with asbestos, if the product is not sold to shoe manufacturers or to their suppliers, shoe manufacturers will not be caught in the scenario.

ⁱ These distributions are often fitted to historical data and adjusted for expert input.

3. Process

3.1 Expert interviews

The consultation process engaged a broad variety of subject experts including casualty brokers, underwriters, claims managers, lawyers and risk managers in high risk industries.

All experts referenced various casualty catastrophes, both historic and emerging. These were then modelled using the scenario methodology outlined in the 2015 paper (Lloyd's, 2015). Each interviewee also received a note of the interview for comment and correction including a shape for each event for their review. The scenarios explored are set out later in the paper with reference to the related shape.

Shapes were parameterised by expert input through iterative expert interviews, assisted by:

- Writing up the narrative as a basis for the next iteration;
- Computer-generated graphics/tables to showcase quantitative information and prompt further input or corrections;
- Model outputs; and
- Historical data.

These initial parameters reflect a plausible set of assumptions, which will continue to evolve in light of further input, changes in the socio-economic environment and to reflect a better understanding of risk.

Whilst the direction of any given observation and which variable it impacts was often established, and while historical data provided a useful baseline, the precise magnitude is much more contentious and often was not known precisely when creating the model.

Where experts provided non-parametric estimates - for example in qualitative terms such as low, medium and high - the model developers used their judgement to quantify those estimates, but the non-parametric information helps establish comparative risk. It is important to note that the process of creating the model is iterative and model releases will be continually refined, based upon the initial version.

3.2 Historical data

Historical data used in this paper refers to a set of more than 380,000 liability events researched by Advisen, exceeding US\$9 trillion in loss value. The data is classified by risk type and insurance coverages, and group loss events by a common cause of loss.

This data was used in conjunction with input from experts who commented on the parameterised shapes and provided opinion on future losses, the kinds of events that may give rise to large casualty catastrophes, and the kinds of factors that may drive future events.

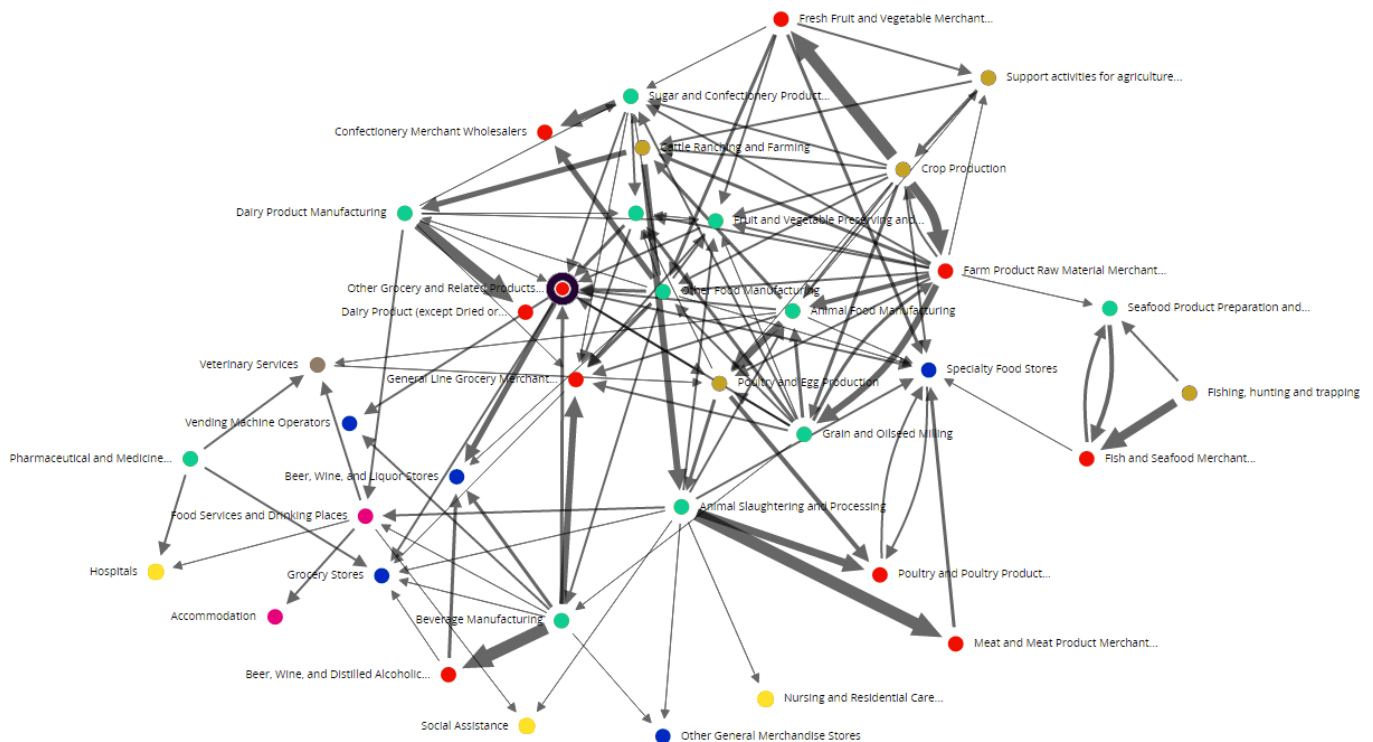
Where there were gaps in the parameters, or experts identified drivers for future loss but could not readily opine on the size of historic losses, or did not anticipate that future losses would deviate in nature from historical losses, the historical data was used as a bridge to augment the expert input. For example, some experts thought industrial accidents were largely caused by human error, and did not anticipate that rates of human error would change over time, although they acknowledged that other factors, such as regulation and risk management, would impact on the frequency and severity of these events.

3.3 Relevant industries

Not all industries connected in the trade map are relevant to a scenario in a particular shape. For example, a roof collapse in a large retail establishment would not implicate suppliers of the food sold in that establishment, but a contamination of food sold in that establishment potentially would. The historical data was used to help understand what industries have been historically implicated in those scenarios. The trade maps were used to help understand what industries might be implicated in the future in those scenarios by helping identify relevant suppliers or distributors of products or services, even if they have not yet been implicated in a historical scenario. For example, in the historical pharmaceutical scenarios reviewed, it appears that supermarkets have not yet paid a loss but some are distributors of pharmaceuticals and it is possible that they might be liable in a future scenario for own brand pharmaceuticals or where a pharmaceutical manufacturer might be bankrupt.

Pre-filtering is very important to exclude industries that are clearly irrelevant to a scenario. The universe of relevant industries then may need to be constrained as, for example, an asbestos manufacturer not only gets supplies from asbestos mining, but also may borrow from its bankers. This last trade may not be relevant to the product scenario and so it needs to be excluded from the potential set of possible implicated industries. In order to achieve this exclusion there are background maps set for different industries within different shapes. The sample background map below (Figure 6) relates to the food industry:

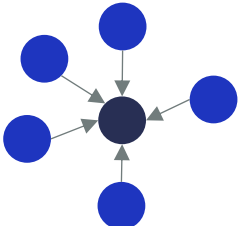
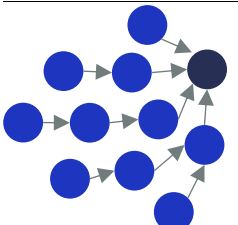
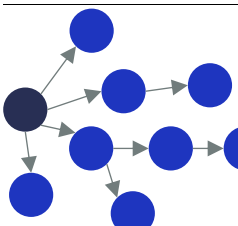
Figure 6: Food industry



4. Shapes

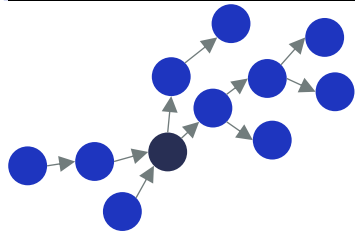
As mentioned, shapes are an innovative way to categorise casualty events. It is not an imposed categorisation, but one that emerges, and may continue to emerge, from the events that are modelled. These categories cross different lines of business, different countries and different industries. Shapes are based on the activities that give rise to the loss such as the nature of the product or service, whether financial products, goods or services, or operations and infrastructure. The events modelled to date fell into one of the following footprint shapes, or a variation thereof, plus a “professional claw”.ⁱⁱ

Figure 7: Shapes

| Shape | Name | Description |
|--|------------------------------|---|
|  | Corporate | Losses: Related to the number of causative parties Line of business: Professional indemnity, D&O Systemic: Mostly single, systemic within an industry Probability ⁱⁱⁱ : Stationary |
|  | Infrastructure/operational | Losses: Divisible between parties Line of business: All but primarily general/public liability, employers' liability/workers' comp, environmental Systemic: Overwhelmingly single, systemic potential within an industry Probability: Stationary |
|  | Product component/ingredient | Losses: Additive Line of business: general/public liability, product liability, also employers' liability/workers' comp, professional indemnity, environmental Systemic: between and also within industries Probability: Non-stationary |

ⁱⁱ This refers to professional or financial services that can be provided up and down the supply chain. These services are only a one step link and they never extend beyond the professional services supplied to their clients.

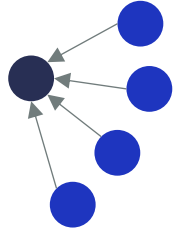
ⁱⁱⁱ Stationary probabilities are relatively stable over time. Non-stationarity is present when the probability of occurrence depends in a significant fashion on factors that are time-dependent. For further discussion on probabilities, see Section 8.3 Occurrence probabilities in the Appendix.



Finished product/service

Losses: Additive
 Line of business: Financial - financial lines, professional indemnity, D&O Other
 product/ service: general/public liability, product liability, cyber
 Systemic: Some single, systemic within an industry
 Probability: Non-stationary

In addition to the shapes above, there is a “professional claw” that can adhere to almost any node in the shapes.



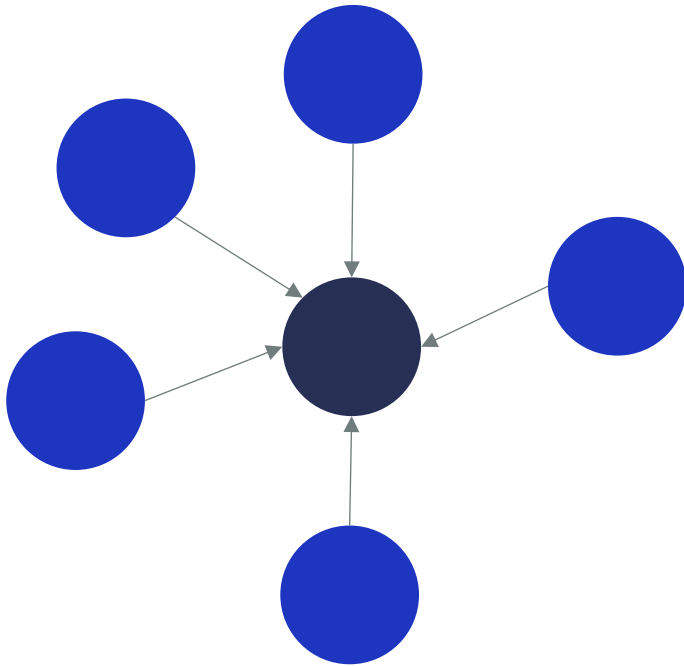
Professional/financial

Line of business: Professional indemnity

4.1 Corporate shape

This shape emerges from corporate activities, e.g. a financial wrongdoing, bankruptcy, fraud or securities class actions, sometimes resulting in the implosion of the company perpetrating it, and involving its professional advisers.

Figure 8: Corporate shape



Its associated parameters are:

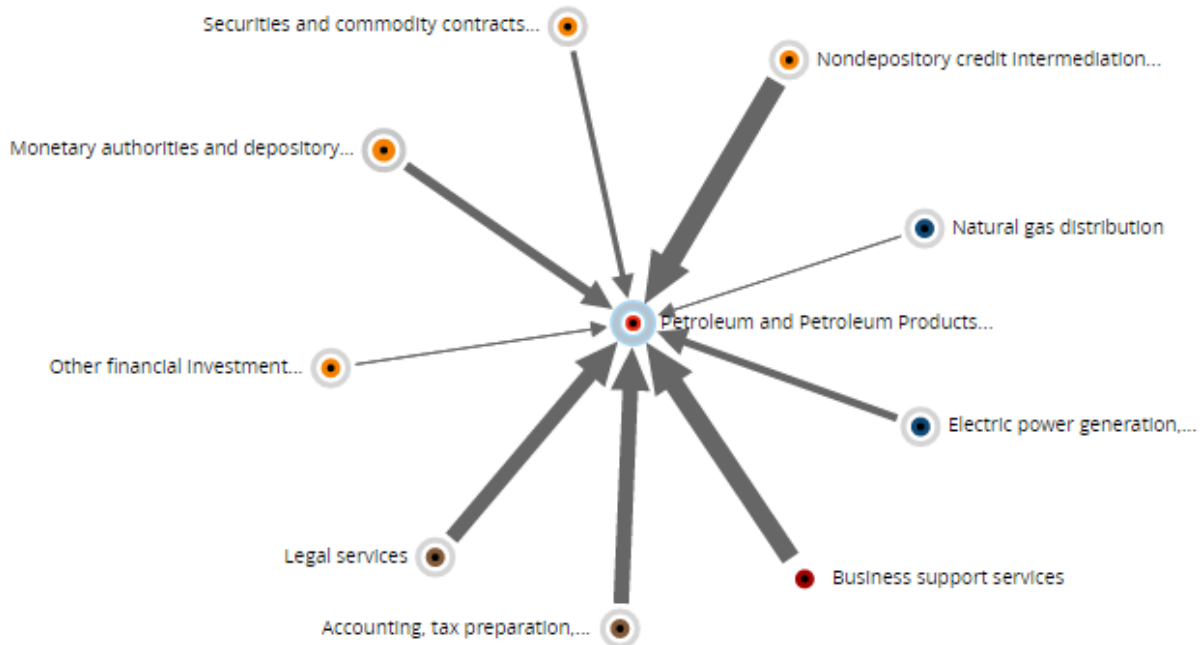
- The losses are proportional to the size of the failed or sued company.
- Most of the losses from a company fraud or bankruptcy are not systemic, but securities actions and some failures (e.g. savings and loans crisis), may be systemic.
- The losses are in proportion to the number of causative implicated companies but will not increase in proportion to the number of advisers or suppliers involved.

This scenario could happen in almost any industry but experts felt was more likely to occur where there were changes in business practices or rapid growth or deregulation. Companies with many off-balance sheet assets were considered to be more vulnerable.

The lines of business usually implicated are professional indemnity, for financial and professional services, and also D&O. Scenarios suggested by experts and historical scenarios analysed include Enron, Worldcom, the savings and loans crisis of the 1980s and 1990s, MF Global in 2011 and the great salad-oil swindle of 1963.

4.1.1 Case study: Enron

Figure 9: Enron supply chain and implicated parties (light grey circle)



4.1.2 Scenario summary

In just 15 years, Enron grew from nowhere to be America's seventh-largest company in 2002, employing 21,000 staff in more than 40 countries and allegedly with US\$63.4bn in assets. But the firm's success turned out to be based on fraud and the company filed bankruptcy.

Enron was hiding the financial losses of the trading business and other operations of the company using mark-to-market accounting. This is used in trading of securities to determine what the actual value of the security is at any moment. In Enron's case, the company would build an asset, such as a power plant, and immediately claim the projected profit on its books. If the revenue from the power plant was less than the projected amount, instead of taking the loss, the company would then transfer these assets to an off-the-books corporation, where the loss would go unreported.

Enron shareholders filed a US\$40 billion lawsuit after the company's stock price, which achieved a high of US\$90.75 per share in mid-2000, plummeted to less than US\$1 by the end of November 2001. The US Securities and Exchange Commission (SEC) began an investigation and rival Houston competitor Dynegy offered to purchase the company at a very low price.

The deal failed, and on December 2, 2001, Enron filed for bankruptcy under Chapter 11 of the United States Bankruptcy Code. Enron's US\$63.4bn in assets made it the largest corporate bankruptcy in U.S. history until WorldCom's bankruptcy the year after.

Various competitors (implicated in projects or market manipulation) and various banks, investment advisers, accountants, and lawyers were sued as professional advisers for collusive involvement in fraudulent transactions with Enron. Enron's auditor, Arthur Andersen, was found guilty in a US district court of illegally destroying documents relevant to the SEC investigation which voided its licence to audit public companies, effectively closing the business.

Many executives at Enron were indicted for a variety of charges and some were later given a prison sentence. By the time the ruling was overturned by the US Supreme Court, the company had lost the majority of its customers and had ceased to operate. Employees and shareholders received limited returns in lawsuits, despite losing billions in pensions and stock prices.

4.1.3 Correlation: economic loss and starting company size

In a company implosion such as the Enron scenario described above the loss amount is correlated to the size of the imploding company. To model this, one can connect the economic loss to the company size by coupling their respective dynamics (i.e. by making one depend to the other).

A straightforward solution is given by the following two-steps approach^{iv}:

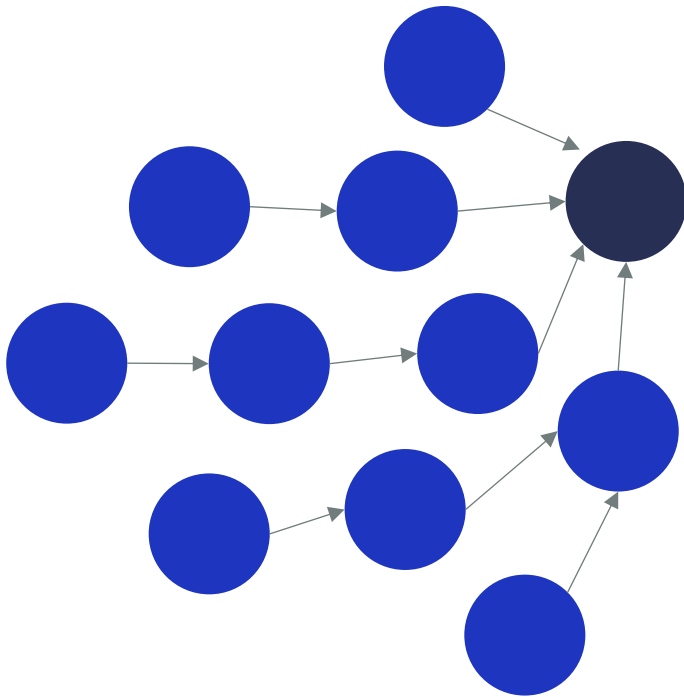
1. Create a model for company turnover for all companies in the economy. Turnover is taken as a proxy for market capitalisation. The model for turnover does not depend on the economic loss model associated with the shape.
2. The model for economic loss depends on the turnover threshold as an input variable. In particular, larger economic losses are associated with larger turnover outcomes from the previous step.

^{iv} In technical terms, this is a two-step procedure where the economic loss is modelled conditional on the turnover distribution, and both are assumed to be beta distributions. More specifically, the shape parameters of the economic loss depend on the turnover, giving the effect seen in the graph.

4.2. Infrastructure/operational shape

These events arise from business operations (not a product) that result in infrastructure accidents or operational losses. The loss, most likely arising from a single accident, explosion or longer term pollution, impacts the contractor or owner of the infrastructure and their suppliers.

Figure 10: Infrastructure/operational shape



The extent of the exposure relates to the nature of the operation and the infrastructure. For this reason it is important to differentiate between:

- Industrial operations, which result in an accident, explosion, or pollution involving for example offshore platforms, power plants, chemical factories, mines, tend to be larger as they have greater environmental and pollution potential, and also have the potential to cause bodily harm to people in the surrounding area as well as on or inside the infrastructure;
- Operations such as passenger ships, passenger aircraft, hotels, bridges, and tunnels and also injuries arising from the very nature of the operation itself (e.g. National Football League (NFL) concussions) tend to be smaller and cause primarily bodily injury to those in the transport, infrastructure or building (and obviously also property damage to that infrastructure).

Usually both result only in a single loss, not systemic (except if there is a common mode of failure, perhaps combined with a cyber-attack) that will be distributed between the implicated companies and it will not increase in proportion to the number of parties. No correlation was found between the number of accounts impacted and the size of the loss. For example, the Deepwater Horizon scenario shows a significant loss born by only few parties.

Almost every line of business could be implicated especially general/public liability, environmental pollution, employer's liability/workmen's compensation but also product liability, professional liability, energy, marine, and even cyber.

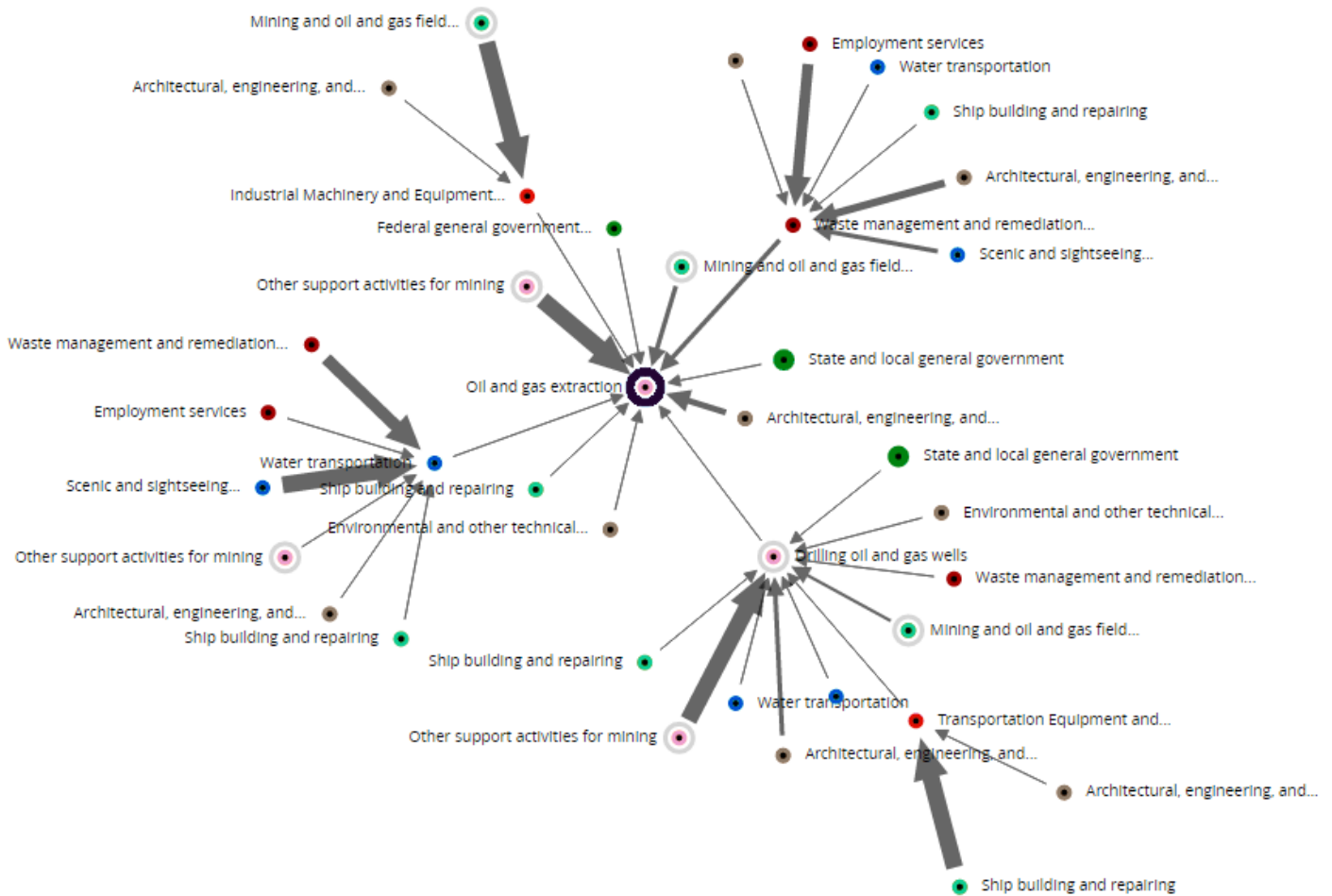
This is the only shape with probabilities that are relatively stable over time (stationary probabilities). This is because the nature of the events, though manmade, are primarily based on accidents or explosions arising more from human error, which is relatively stable, rather than changes in technologies, regulations or societal norms, although the degree and effectiveness of risk management and other mitigation may vary between industries and jurisdictions.

Experts recognised that regulation tends to correlate with jurisdiction so the frequency of loss is reduced in countries with developed regulatory frameworks and, similarly to property cats where infrastructure can be made more resilient to earthquakes or hurricanes, risk management can help limit the severity of infrastructure events.

Scenarios mentioned by experts and historical scenarios analysed include Deepwater Horizon, Costa Concordia, the 2006 Ivory Coast waste dump, the 1981 Hyatt Regency walkaway collapse, the BP Texas City Refinery explosion, the 2006 Mecca hostel collapse, the West Texas Big Spring explosion, NFL concussions, Bhopal, the Buncefield explosion, the Toulouse Fertiliser explosion (also known as the Total SA Fertiliser explosion), Exxon Valdez and the Lac Megantic derailment.

4.2.1. Case study: Deepwater Horizon

Figure 11: Deepwater Horizon supply chain and implicated parties (light grey circle)



4.2.2 Scenario summary:

The Deepwater Horizon explosion occurred on 20 April 2010 and resulted in the world's largest oil and gas spill. The incident led to the death of 11 individuals, numerous personal injuries and the release of millions of gallons of oil into the Gulf of Mexico. Economic losses to date are approximately US\$52.4 billion and consist of costs for the extensive four years clean-up, environmental and economic damages and penalties.

On 20 April, the ultra-deep-water, semi-submersible mobile offshore oil rig (Deepwater Horizon) experienced an explosion and a fire, and sank in the Gulf of Mexico, off the shores of Louisiana. The rig was owned and operated by Transocean, a Switzerland-based offshore drilling contractor, and leased to BP.

The blowout and oil spill was caused by a flawed well plan that did not include enough cement between the seven-inch production casing and the 9 ⁷/₈ inch protection casing (The Bureau of Ocean Energy Management Regulation and Enforcement, 2011). The safety-test failures of the well integrity led to the loss of hydrostatic control. Ultimately the weakness in the cement design and testing, quality assurance and risk assessment caused the blowout to occur (British Petroleum, 2010).

The explosion and fire occurred in spite of specialised oil-spill prevention equipment called blowout preventer (BOP) designed to avert this type of disaster. The failure of the BOP left the well unsecured and leaking from the marine riser. The amount of oil and gas escaping from the subsurface well is a matter of dispute, but an interagency federal panel of scientists led by the US Geological Survey estimated the spill's size in the range of 35,000-60,000 barrels of oil a day.

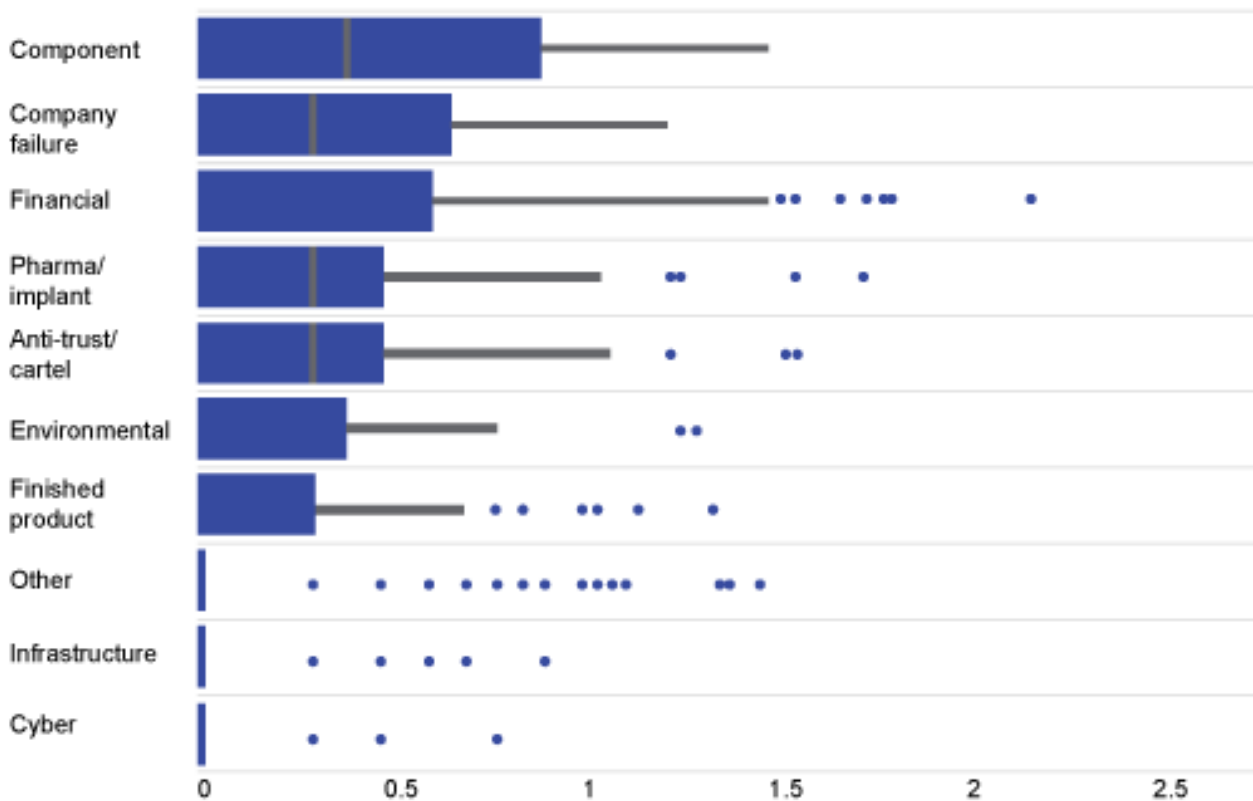
Two separate class-action settlements were agreed upon. The first compensated individuals and businesses that suffered private economic loss as a result of the spill (including lost profits and property damage). The second compensated people having medical claims in connection to the spill and also provided them with 21 years of regular medical consultation. In addition, there were several billion dollars paid in connection with long-term clean-up issues and payments to states such as Louisiana, Texas, Florida, and Mississippi for economic damages (St. Myer, 2015). There was litigation in other countries such as Mexico and litigations over, for example, royalties for lost oil that contributed to a foundation, fines donated to foundations for restoration work, and harm to endangered or threatened species in the Gulf (Fausset, 2010).

4.2.3 Relationship between shapes and systemic events

One of the defining features of this type of infrastructure scenario is its containment within supplying industries. Few parties are typically implicated in any given industry for a given loss event. In this sense, scenarios are not systemic as this defines any event that involves a multiplicity of parties sued and multiplicity of industries that they are part of.

The following chart shows this by illustrating the average number of parties found liable per industry per scenario (charted on a log-10-scale in order to make charting tractable). Infrastructure is the second from the bottom and most of the values are zero on a log-scale – which demonstrates that most of the time, there is just a single party implicated.

Figure 12: Count of parties per industry

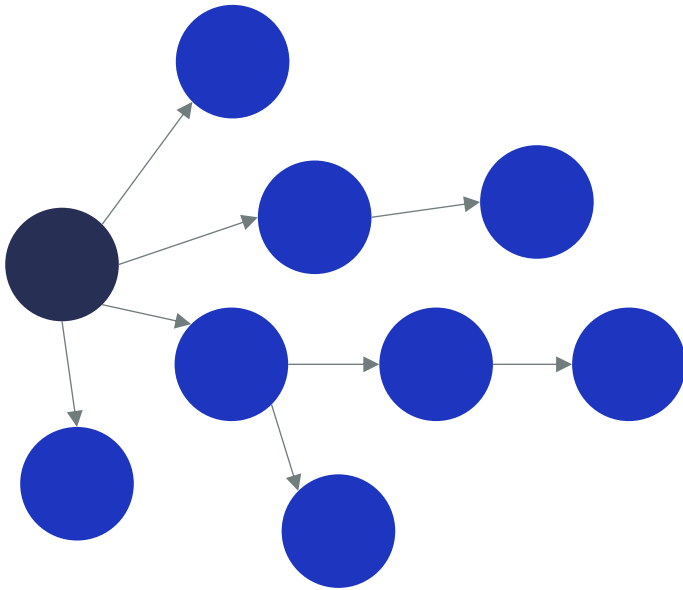


This is in contrast with the more systemic types of risks such as financial or product-related exposures (component, financial and finished product) where the median count is well above just a single party.

An interesting observation in this respect is cyber risk. To date, this risk was relatively contained within industries (hence the low average number of parties in the chart above), but some authors (World Economic Forum, 2016; Centre for Risk Studies, 2014) have pointed to the possibility of systemic liability catastrophes resulting in this category of cyber to rank higher up in the graph. This is another example where expert input can be used to modify historical record to reflect emerging issues.

4.3 Product/service shapes

Figure 13: Component/ingredient shape



There are two product shapes:

1. Components and ingredients; and
2. Finished products and services.

The major difference between these shapes is the potential impact of the event. The spread *between* industries is more restricted if limited to a particular finished product (e.g. a breast implant) compared to something that is found in a number of products (e.g. calcium aluminate cements). The spread within an industry - for example the PPI mis-selling loss - could be extensive in either shape. For either shape, events could be a single event, starting with a company fraud or single contamination, such as Madoff or contaminated cantaloupe, or a systemic event, affecting many industries and many parties within an industry, such as silica or the rigging of the London Interbank Offered Rate (LIBOR) rates.

For both shapes a correlation was found between the number of companies impacted and the size of the economic loss. That is to say that the greater the number of industries and products are impacted, the more likely consumer impact and losses will be more widespread.

4.3.1 Component/ingredient shape

This shape is most likely to give rise to the largest losses and it is potentially the most systemic. This is due to the fact that a contaminated or faulty product component or ingredient close to the beginning of the supply chain can cascade through the supply and distribution chain impacting numerous finished goods and potentially implicating a wide number of insureds in a wider number of industries.

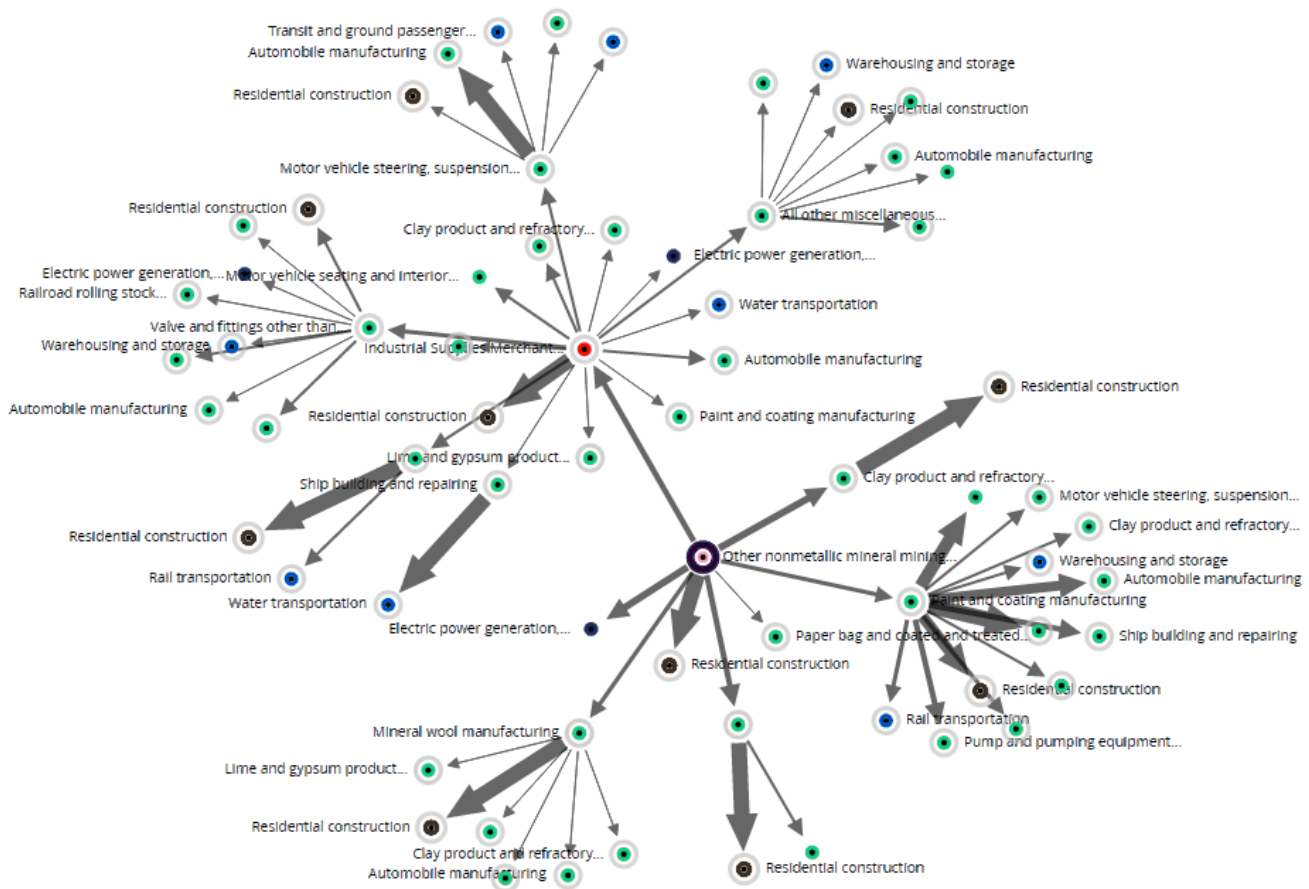
The lines of business primarily implicated are general/product liability but also employer's liability/workers' compensation, professional indemnity and even environmental. This is the shape of asbestos and of many emerging risks such as nanotechnology, BPA and food additives. The potential scope of the event depends on:

- The spread of the exact ingredient. This is captured in the underlying trade maps. For example, asbestos may be used more pervasively than talc.
- The place in the supply chain. In general the further up the supply chain the component or the ingredient is, the more potential products may be impacted and the more consumers may be affected.
- Whether the faulty component or ingredient is detected and recalled before it is purchased by consumers (see Section 8.2.2.5 Product recall/traceability, p36, on the Sudan 1 red dye product recall). Regulation, traceability and batching can reduce the frequency of the product reaching the consumer, though a product can also cause employee liability during manufacture and installation of various products as asbestos did.
- The nature of the product itself. Less valuable, smaller and ubiquitous components or ingredients such as dyes, food additives or silica may be incorporated in numerous products and have a wider impact.

Scenarios suggested by experts and historical scenarios include asbestos, a cattle-cake loss from contaminated feed, fridge-freezer defrost timers overheating, the 2013 UK horsemeat scandal, the 2011 e-coli outbreak in Germany, the red food dye Sudan 1, fire-retardant in animal feed, sugar as an emerging risk, soya milk, silica, calcium aluminate cements, lead paint in toys and construction, the Takata airbag recall and contaminated cantaloupe in 2011.

4.3.1.2 Case study: Recent asbestos losses (since 2007)

Figure 14: Recent asbestos losses and implicated parties (light grey circles)



4.3.1.3 Scenario summary

This is a good example of a truly systemic casualty catastrophe. Asbestos had been used since the end of the 19th century. It was already thought to be causing some personal injuries by 1929 and over the decades until 1970s and 1980s was ubiquitous particularly as an insulation material, used in hundreds of industries. Losses since 2007 are around US\$13bn, while total losses to date are around US\$100bn (A.M Best, 2016). Anticipated losses are expected to reach US\$200bn or even US\$275bn. Latency periods after exposure to asbestos can be up to 50 years.

This scenario primarily covers industries in the US, which currently account for about 90% of the losses from claims filed since 2007.

Many of the initial companies sued went into bankruptcy. The shape of the industry has altered, with asbestos mining and manufacturing in decline and other industries being created (e.g. remediation services and asbestos masks) which have given rise to new litigations.

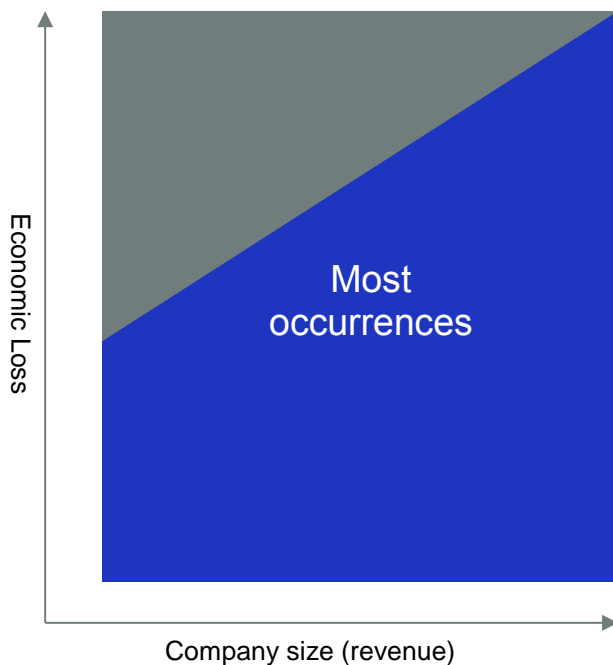
4.3.1.4 Distribution of losses between parties

One key parameter is how losses are distributed between parties of different sizes.

At a macro level, reviewing all events, including those with one or a few parties, the historical data observed shows that below a certain size of economic loss, the size of the player did not appear relevant to who bore the loss. However, over a certain threshold of loss, larger losses are typically paid by larger companies (see Figure 15).

This type of correlation is strong for “Component/ingredient” or “Finished product” type shapes but much less pronounced for “Infrastructure”.

Figure 15: Distribution of losses



Experts also made a number of observations relevant to the distribution of losses between parties. Some observed that where there is a large corporate in a loss scenario, it could face a larger share of the claim, especially when the loss exceeds the capacity of the smaller players. Some also observed that in certain industries - e.g. pharmaceuticals, oil and gas, banking - the corporate itself, for reputational reasons, may be willing to assume liability^v, or those reputational issues may make the courts more likely to find the large corporate to be liable. Conversely, it was also observed that a large corporate could use its bargaining power to get smaller players to assume liability for losses.

The historical data was examined for certain events with multiple implicated parties to see if the presence of one or a few larger parties tends to spread the loss. This pattern was found particularly with respect to:

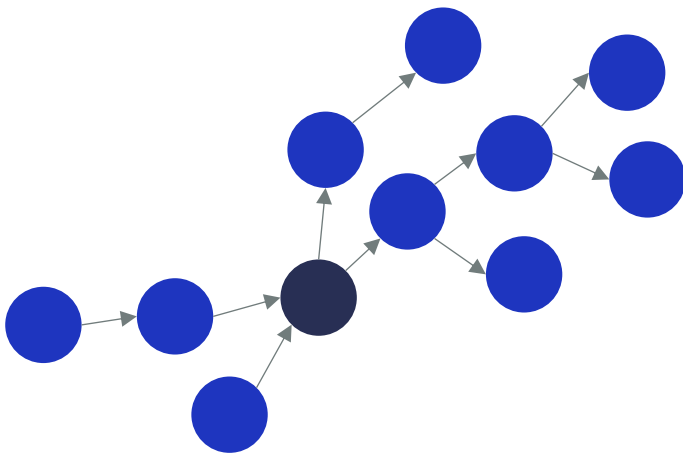
- the component/ingredient shape discussed in this section (“component”);
- the finished product shape with respect to events involving financial institutions (“financial”), discussed in Section 4.3.2 (see p26); and
- the infrastructure/operational shape with respect to events having an environmental impact (“environmental”) discussed in Section 4.2 (see p19).

See Section 8.2.3.6 (p39) in the Appendix for further details.

4.3.2 Finished product/service shape

This shape starts with a faulty finished product, including financial products and software services. It is limited in impact to that good or service, but it does implicate suppliers (of both services and materials) and distributors. It can be systemic within those industries and potentially creates large losses depending on the product or service. Usually implicated are financial lines and professional indemnity for financial products, general and product liability for other products and services, and also cyber where a software service is involved.

Figure 16: Finished product/service shape



The apparent systemic nature (within an industry) of many of the financial events such as LIBOR and Forex rigging, PPI and pension mis-selling and subprime, was discussed with experts (see Section 4.1, p16 for the IPO laddering cases, savings and loans crisis of the 1980s and 1990s). They saw the systemic nature of these losses arising from a common modus operandi: a fallacious shared business model combined with flawed practices and conduct failures.

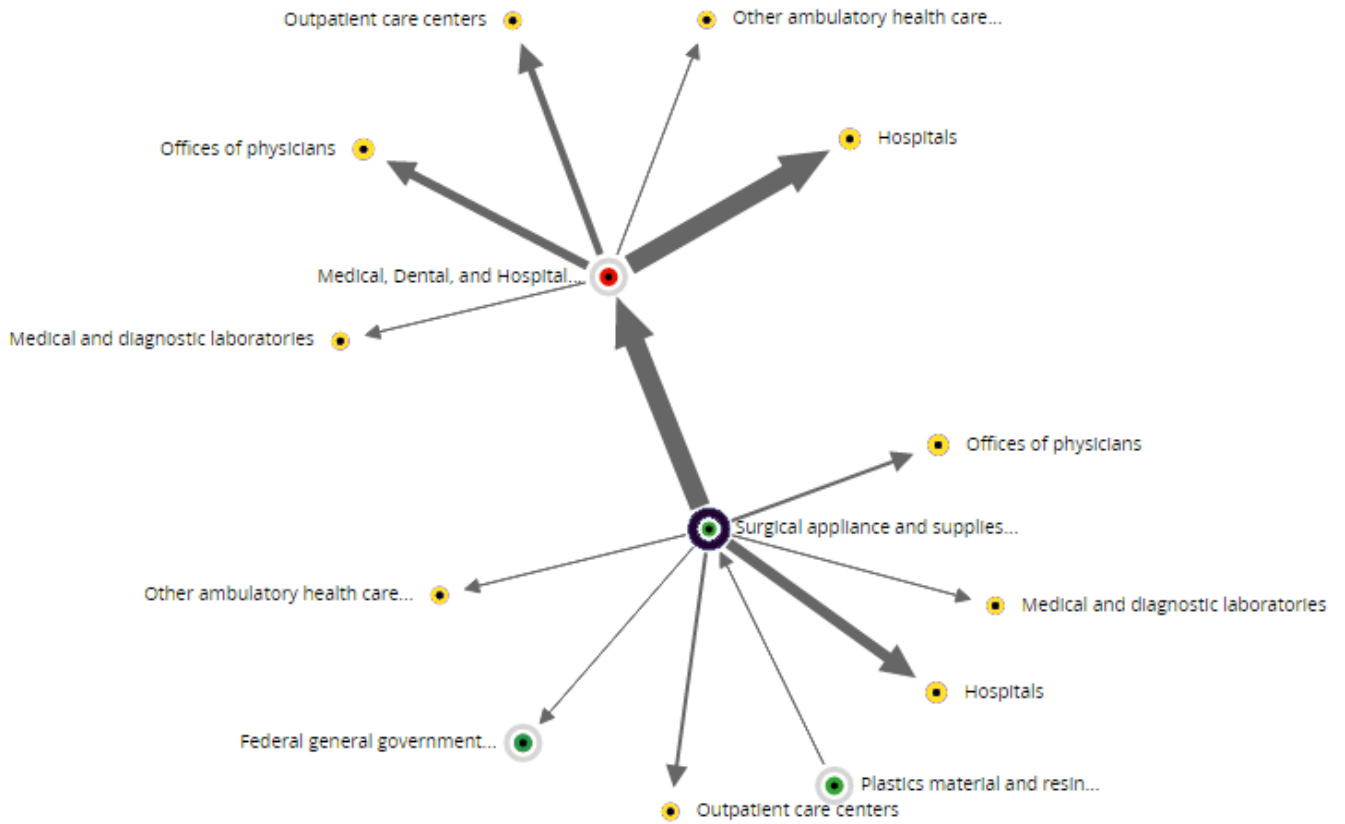
Although criminal acts as underlying Ponzi schemes, LIBOR and Forex rates-fixing are not covered by insurance, the fallout may be in terms of D&O/PI claims.

In this shape, the manufacturer or producer of a finished good may be primarily responsible for the faults, but some suppliers as well as distributors may be implicated. As such, this is a more contained and less potentially systemic event between industries than the component/ingredient fault shape as it primarily relates to one type of finished goods, but an event could be widespread within those industries.

Scenarios suggested by experts and historical scenarios analysed include LIBOR-fixing, PPI miss-selling, silicone breast implants, cigarettes, Thalidomide, the 2008 Chinese infant formula milk scandal (melamine), damaging fertiliser in South Africa, Kitec plumbing, Bacardi benzene, Electromagnetic fields (EMF) – mobile phones, Firestone Ford tyres, Toyota unintended acceleration, Chinese drywall, subprime – Lehmann's, hip/knee replacement defects, Fen-Phen and AWS DDOS event and Madoff.

4.3.2.1 Case study: Silicone breast implants litigation

Figure 17: Silicone breast implants supply chain and implicated parties (light grey circle)



4.3.2.2 Scenario summary

Litigation in the 1990s that would cost the industry US\$11.2bn, and an FDA ban on any silicone implants for cosmetic purposes, led to all but two small manufacturers departing the silicone breast implant business and the largest manufacturer, Dow Corning, filing for bankruptcy. Nevertheless there is still no scientific evidence that the implants cause serious disease.

The significant size of the losses, the widespread anxiety created about the implants, and the absence of a causal connection with serious injuries has raised concern about how the regulatory and judicial system operated in this context (Miller, 2015; Shiffman, 1994; Kolata, 1995).

4.3.2.3 Distribution of finished product losses between industries

For finished goods (excluding cyber and financial products), typical distribution of losses was analysed and related to the overall loss from the event. The bar charts below are organised by percentiles of total event losses, the 95% percentile, for instance, modelling only the 5% largest loss events. Industries are categorised into

manufacturers, outlets, wholesalers and professional services. Outlets in this case are industries that distribute finished products to consumers (e.g. retailers and restaurants). Figure 18 shows the share each category has in terms of total casualty losses (across all events in the historical loss data base) for “Finished products”:

Figure 18: Historical share of total casualty losses for “Finished products” by industry

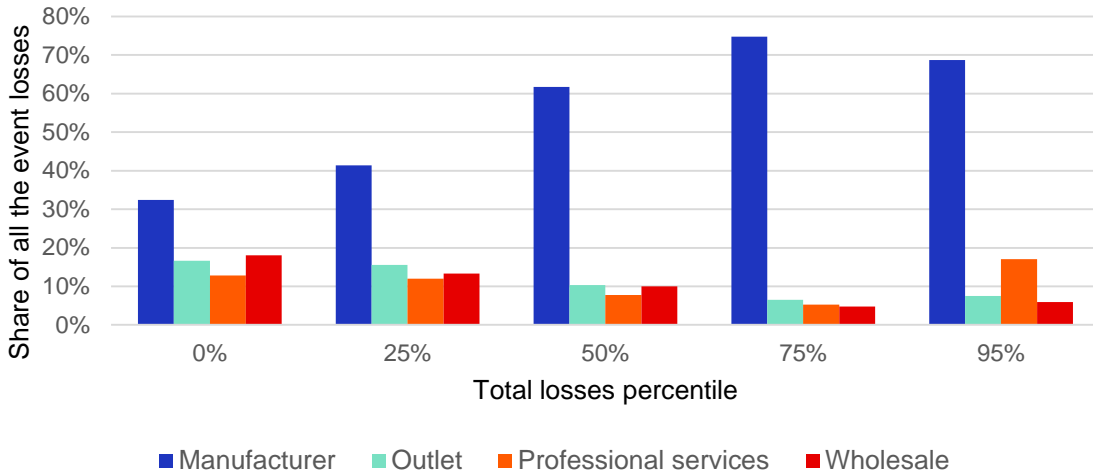
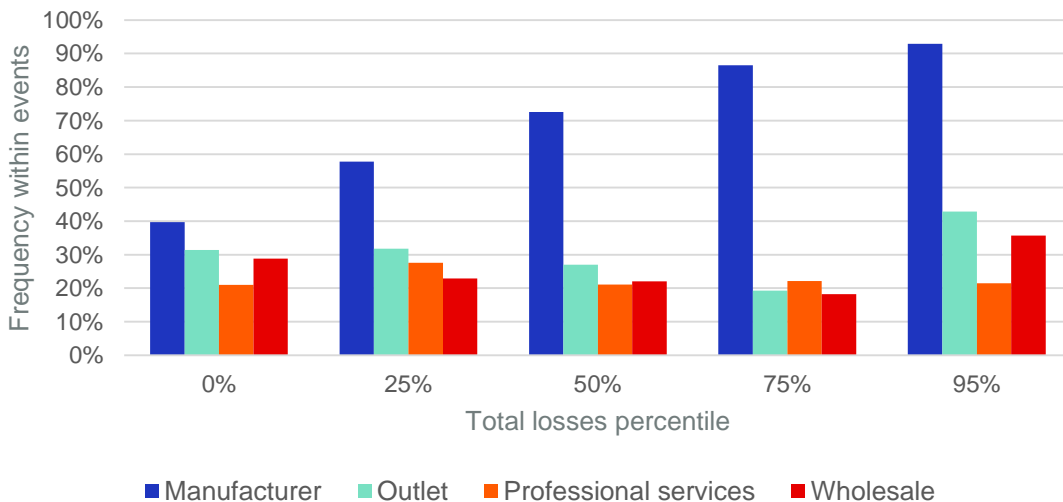


Figure 18 illustrates that manufacturers bear the majority of losses in this type of scenario, and that their share increases when the overall event loss increases, going from ~30% to 60%-70% for large losses.

Figure 19 shows how often a certain industry is implicated in an event. In particular, manufacturers are much more likely to be brought into a “Finished product” event than any other sector, which is consistent with expert input.

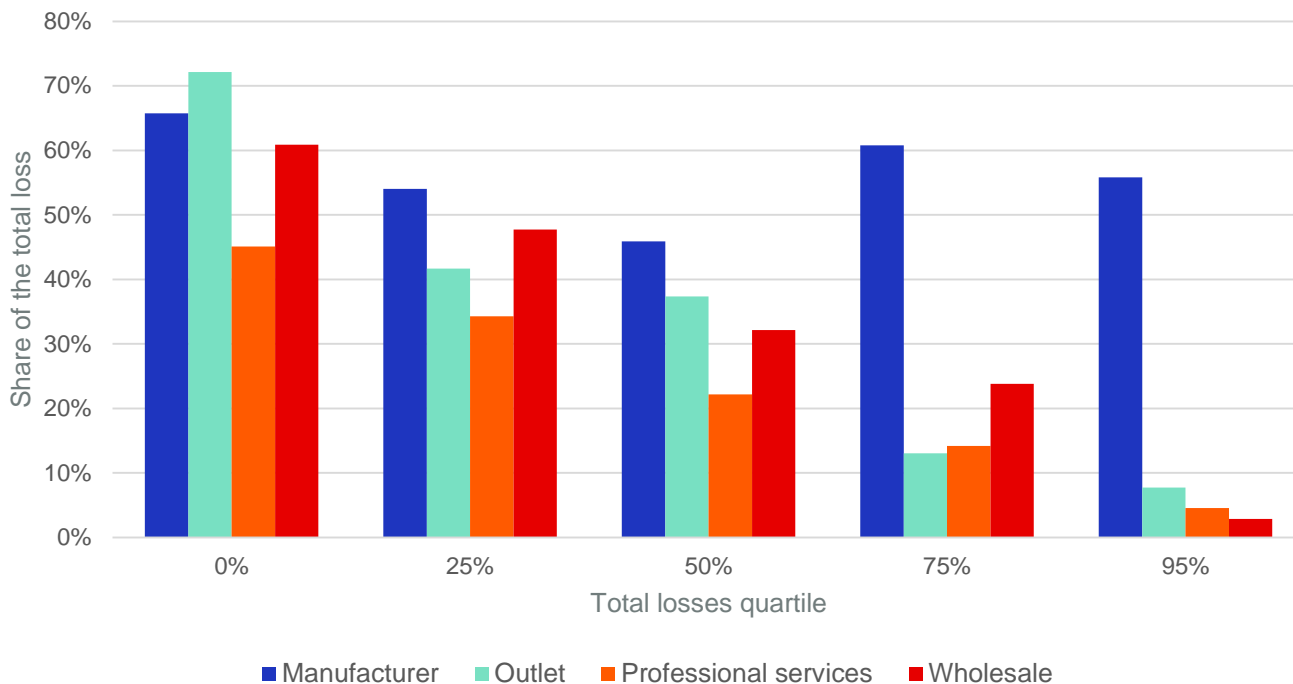
Figure 19: Frequency of total casualty losses for “Finished products” by industry



Interestingly, the frequency with which other industries (outlets, professional services and wholesale) are implicated is not that dependent on the size of the loss, and it is generally between 20% and 30%.

Considering the share of loss, Figure 20 illustrates what share of the overall event loss an industry bears *if* it is implicated in the event.

Figure 20: Severity for “Finished product” events expressed as share, by industry

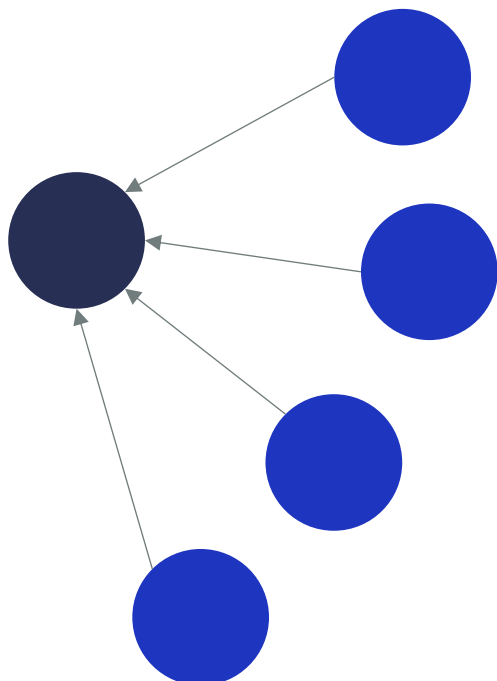


Where the overall loss is smaller, loss severities are relatively evenly distributed - i.e. manufacturers are not likely to pick up more of the losses relative to other industries in the same event.

For larger events, however, manufacturers do receive a consistently higher share of the culpability relative to other industries in the same event.

4.4 The “professional claw”

Figure 21: “Professional claw”



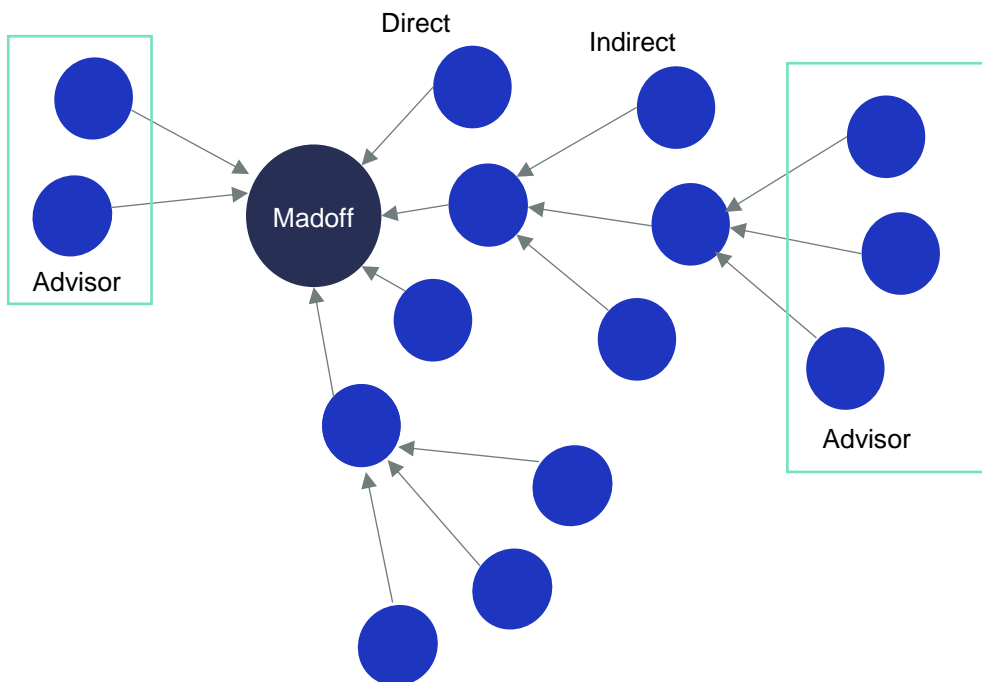
It is important to notice that professional services can be supplied at any stage of the supply and distribution chain for any given product or in any shape.

The services supplied depend on the product and could be financial, legal, accounting, testing, engineering, design services etc. and, accordingly, the relevant line of business is professional liability.

Usually professional advisers are held solely responsible for the advice they provide and for the choices they make about who or what sources to rely on when providing that advice. Moreover, professional services may not always be supplied by external professionals but from within an organisation (e.g. testing provided by a manufacturer, actuarial advice to an insurer provided by internal rather than consulting actuaries) resulting in a decrease of the frequency of the external professional service claw.

As mentioned, the claw is not a standalone shape except in the context of fraud and bankruptcy such as Enron, and it usually “hangs off” another shape. For example in the Madoff scenario below, the circled supply of services are the ‘professional claws’.

Figure 22: Occurrence of “professional claw” shapes



5. Use of parameterised shapes to generate future scenarios

One of the critical aspects of shapes is their ability to describe future and emerging risks as well as types of past events. In this example involving food events, the scenarios and drivers mentioned by experts informed the shapes and parameters that could lead to significant and widespread future food events.

5.1 Food-related scenarios

Seven out of the 12 product-based scenarios mentioned by experts related to food. This seemed surprising as a review of the historical casualty cat losses confirms that there have been few recent large historic food-related events in the developed world. However, by applying the drivers mentioned by the experts to the food-related scenarios, there appears to be potential for significant future losses.

- **Near misses:** In the Sudan 1 red-dye loss, products were recalled before reaching the consumer. The UK 2013 horsemeat scandal turned out to be mislabelled food rather than harmful food. Both “near miss” events demonstrate the cascading effect of ingredients through the supply chain and widespread distribution across national boundaries. Formal analysis of the events and asking counterfactual questions about these near-misses could help underwriters get significant additional insights into extreme losses and reduce future market surprises (Woo, 2016).
- **Food-related losses in the less developed world:** In 2008, a nitrogen-rich substance known as melamine was added to milk, particularly infant formula, affecting tens of thousands of infants in China. Melamine had sometimes been illegally added to food products to increase their apparent protein content and it is known to cause renal failure and kidney stones in humans and animals (International Risk Governance Council, 2010).

- **Food-related losses in previous decades:** In 1973, a fire-retardant chemical called polybrominated biphenyl (PBB) accidentally got mixed into livestock feed. The accident was not recognised until long after the bags had been shipped to feed mills and used in the production of feed for dairy cattle. Studies estimate 70-90% of people in Michigan had some exposure to PBB from eating contaminated milk, meat and eggs. The Michigan Department of Community Health (MDCH) says the “overwhelming majority of those who were exposed to PBB received very low levels”. However, some individuals had higher exposure (40 years after toxic mix-up, researchers continue to study Michiganders poisoned by PBB, 2014).
- **Food-related emerging risks:** There are a number of emerging risks related to food additives (e.g. phosphates and nitrate), to plasticisers used in food packaging (BPA), to other technology introduced into the food chain such as nutraceuticals and to changing society awareness such as the amount of sugar and salt in food.

5.2 Emerging risk: sugar

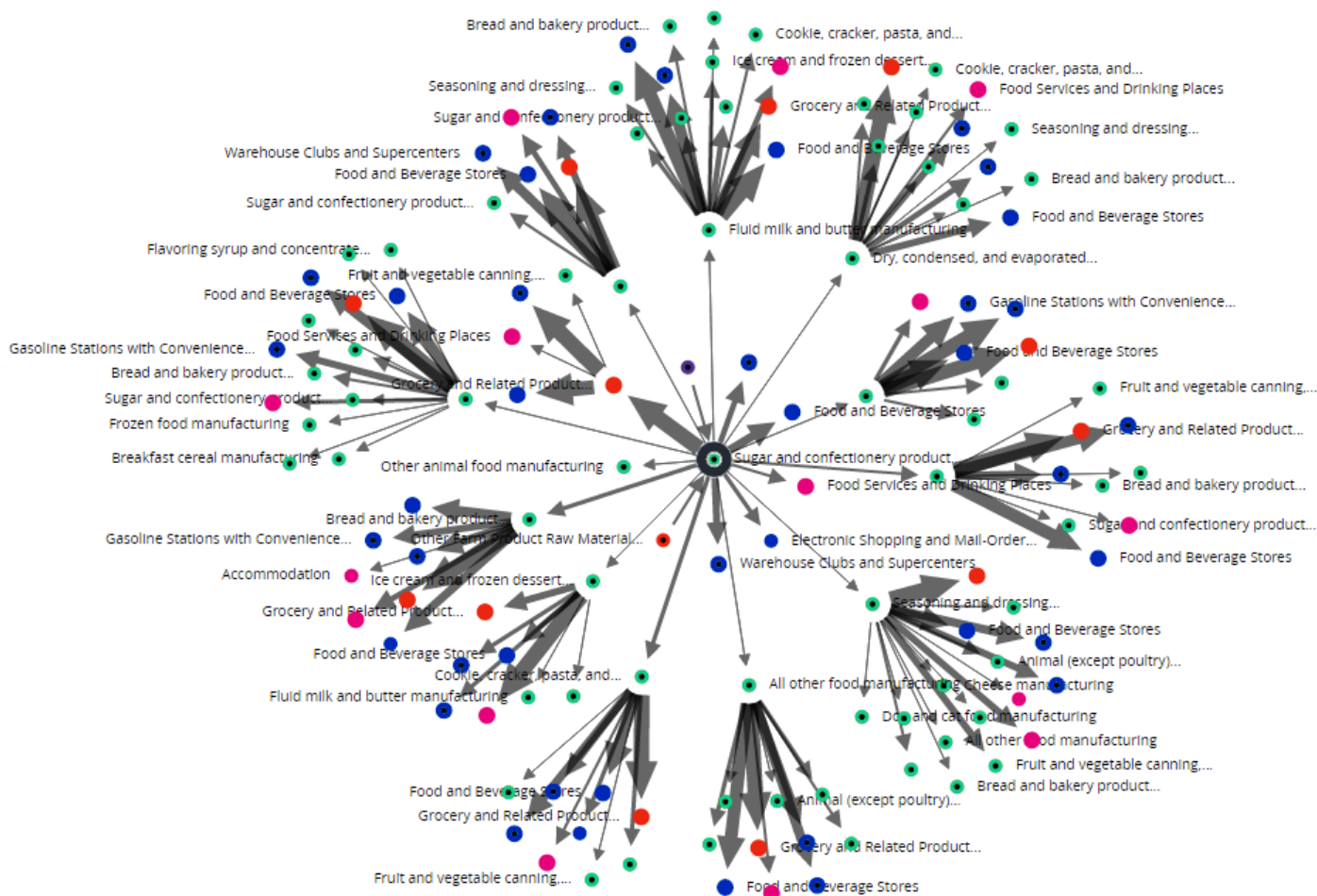
One example referred to by an expert as the “next tobacco” is the potential loss from excessive, but not always obvious use of sugar (also salt) in food *if* excessive levels of sugar were found to be harmful by scientific studies and courts found food producers and/or the distribution chain liable for resulting damages. The view was that a societal shift may make the addition of significant amounts of sugar to our food unacceptable, with liability risks affecting food manufacturers (and possibly distributors and retailers).

A sample footprint, starting from sugar beet and cane farming to sugar and confectionary manufacturing and then spreading to various other food manufacturers, wholesalers, retailers, and food and drink outlets is shown below.

The parameterised shape implicated here is the component shape, which is seen to have the greatest potential for systemic loss. When overlaid onto the trade

map, the widespread distribution of sugar within the food industry and the potential to impact many consumers becomes apparent (Figure 23).

Figure 23: Sugar distribution in the food industry



The nodes represent different industries (using North American Industrial Classification codes – NAICS). Green nodes are (food) manufacturers, red nodes (food) wholesalers, blue nodes (food) retailers, pink nodes other food outlets and the red nodes the growing of cane/beet sugar.

Considering the drivers cited above and mentioned by experts, it seems that latent damage caused by the widespread distribution of sugar in a number of different food products could lead to a systemic scenario. Technically speaking, this would materialise in a number of different parties being implicated in a variety of different industries. Consequently, losses would spread through the supply chain in accordance to the structure of

the trade data emanating from a particular starting industry, in this instance sugar beet and cane farming. For this shape, all relevant supply chains could be implicated, not just the strongest trades, on the premise that quite often, it is cheap ingredients that could be harmful. Historical data suggests that the spread would also be amplified by the presence of large corporates with large insurance cover and funds.

6. Outputs

6.1 Exceedance probability curves

The methodology described in this report can produce a full probabilistic loss curve – in particular, it can deliver annual average losses and arbitrary loss quantiles. These loss curves are often used for insurance rating and capital-setting purposes.

6.2 Heat maps and clusters

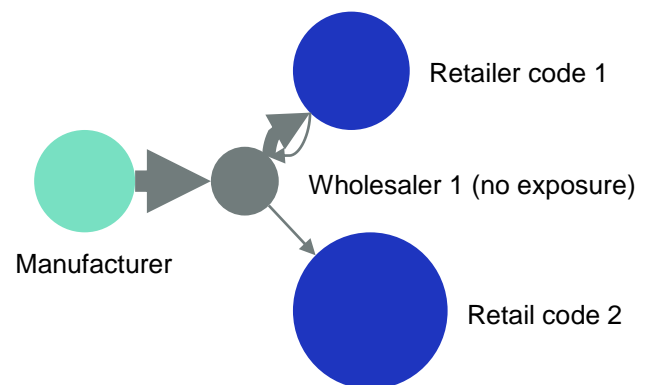
Heat mapping is the overlay of the output from the stochastic model onto the economy. In particular, the goal of this section is to outline further uses of the outputs with a view towards visualisation, identification of clusters and heat mapping.

The underlying idea is to create mappings where:

- The sizes of nodes indicate the value of risk metrics, or contributions of an industry to the portfolio-level value.
- Arrows are used to indicate the correlation between industries. For example, for each adjacent pair of industries, how often these two nodes are implicated in the same event could be computed. Link strengths can then be defined in terms of return periods: rates of coincidence for events exceeding a certain return period.

Areas of the economy where sizes and arrows are prominent indicate risk clusters. For example, consider a simple economy with one manufacturer, one wholesaler, and two retail codes (e.g. supermarkets and gasoline stations) in a notional insured portfolio:

Figure 24: Simple economy example



The wholesaler is greyed out, as in the notional portfolio no policies were written in this industry. Nevertheless, it forms part of a cluster given by a manufacturer, a wholesaler and a retailer – retailer code 1. This cluster may outweigh the risk given by retailer two, who is weakly connected, but has a higher loss metric as a standalone node

7. Conclusions

The basic ideas underlying this paper flow from the report “Emerging Liability Risks - Designing liability scenarios” written jointly by Arium and Lloyd’s in 2015 (Lloyd’s, 2015), where causes and conditions of catastrophic accumulation risks for liability insurance and a methodology to quantify them was explored.

Casualty risks accumulate in a variety of different ways and affect multiple lines of business. Using expert input, corroborated and augmented by historic data, certain distinct types of liability “storm tracks” were observed, which are called shapes. These shapes can describe a multitude of narratives when overlaid on an economic map, providing building blocks to help model historical and future casualty events in a systematic way.

The model and process presented here are a big step forward in the journey of understanding liability risk exposure. These shapes are used to create a large catalogue of scenarios, including potential mega- liability events that exceed asbestos. As a result, the approach allows a fully probabilistic view and returns all the outputs familiar from property catastrophe modelling. It can produce an EP curve that can deliver annual average losses and arbitrary loss quantiles, as well as heat maps/hot-spot analyses that make potential accumulations instantly recognisable.

Future areas of research could expand and enhance this model along several dimensions:

- One reason why the shapes concept is useful is that it reduces the overwhelming complexity of liability risk into discrete building blocks that can be handled one-by-one. Inevitably, however, doing so runs the risk of oversimplification and approximation. Also, the nature of liability risk may change over time. It is therefore important to keep an eye on whether the given catalogue of shapes should be refined or kept, should be adapted or left unchanged.
- In terms of the parameters and mechanics for each shape, future refinement may be desirable or necessary in order to reflect the reality of liability risk. In particular, parameters informed by expert input are currently more set in terms of directionality of the effect and lack an associated magnitude. Future research may help to further pin down the set of parameters best suited to model a particular shape. In particular, the various shapes of some forward-looking risks such as cyber could be further explored.
- Similarly, probabilities associated with each shape will be subject to monitoring and observation through further expert elicitation, in particular with emerging risks experts.
- There are currently insufficient non-U.S. events in the database used for an analysis on distribution of liability by jurisdiction but this would be a useful analysis when further information is available.

8. Appendix

8.1 Scenarios used

The modelled scenarios used to help derive the footprint shapes in this paper were based on scenarios mentioned

by experts and also historical scenarios using data from the Advisen database.

8.1.1 Scenarios mentioned by experts

Table 1: Scenarios

| Historic scenarios | | Emerging/emergent risks |
|--|---|-------------------------|
| Lead paint | Bhopal | Silica |
| Kitec plumbing | Fire retardant in animal feed | EMF |
| Deepwater Horizon (mentioned twice) | Savings and Loans D&O | Arctic |
| Costa Concordia | Red food dye Sudan 1 | Soya milk |
| PIP breast implants | Horsemeat scandal | Sugar emerging risk |
| Owens Corning fibreglass | Damaging fertiliser in South Africa | |
| 2008 Chinese milk scandal (melamine) (mentioned twice) | Fridge freezer defrost timers overheating | |
| 2006 Ivory Coast waste dump | Big Spring Refinery explosion | |
| Berkeley California balcony collapse | Bacardi Benzene | |
| Calcium aluminate cements | Great salad oil swindle of 1963 | |
| Asbestos | Mysterious cattle cake loss | |
| Earl of Malmesbury vs Strutt and Parker | Love canal | |
| Thalidomide | Libor rigging | |
| Enron | Tobacco | |
| 1981 Hyatt Regency walkway collapse | PPI misselling | |
| 2006 Mecca hostel collapse | 2011 E-coli outbreak in Germany | |
| NFL concussions | | |

8.1.2 Scenarios modelled on historic data

Table 2: Scenarios modelled from historic data

| Scenarios | | |
|----------------------------|--------------------------------|---------------------------------------|
| Lac-Megantic derailment | Contaminated cantaloupe 2011 | Takata airbag recall |
| Buncefield explosion | Hip/knee replacement defects | Lead paint (construction) |
| Sony Playstation hacks | Dow corning breast implant | Asbestos ((limited) claims from 2007) |
| Target payment card breach | Lead paint in toys | Fen-Phen |
| Enron | Chinese drywall | Firestone Ford tyre |
| PPI misselling | Piper Alpha | Toulouse Fertiliser explosion |
| Libor rigging | Deepwater Horizon | Exxon Valdez |
| Subprime – Lehmann’s | Toyota unintended acceleration | |

8.2 Experts' observations

Historical data does not reveal what factors actually drove a loss, nor how losses might play out differently in the future. The views gleaned from experts and confirmed by historical data helps inform the drivers and mitigation for the frequency and magnitude of loss, the distribution of the loss and the impact of jurisdiction.

Expert inputs on these factors were overwhelmingly consistent and their individual and unattributed comments are reflected in the factors set out below. The historic data available was used to examine and confirm whether there have been correlations between those factors. The application of the parameters when combined with shapes can help to show how future scenarios might differ.

The factors below are a subset of important factors raised by the experts. They also do not cover in depth matters of general research particular to liability insurance, such as how economic downturns often have an adverse impact on an insurer's bottom lines. The parameters also do not address legal issues such as the impact of laws on joint and several liabilities in the US, which can shift payment from culpable parties with insufficient funds to pay the claims to other parties.

It is anticipated that these parameters will be reviewed, augmented and developed over time.

8.2.1 Risk drivers

8.2.1.1 Societal sensitivities/reputation

It was remarked that societal sensitivities tend to drive the magnitude of liability events, and environmental impact is now a major source of regulation and liability.

The industries whose activities are perceived to have an adverse impact on the environment, on health and safety or otherwise appear to be socially sensitive (e.g. mining, oil and gas, pharmaceuticals/medical, automobiles, banking, financial services and food). As such, they appear to be susceptible to large accumulation losses, and are more likely to be held responsible for those losses with consequent adverse reputational impacts.

8.2.1.2 Societal awareness

It was observed that although the asbestos loss was partially related to the number of people impacted by it, even if not actually harmed by it, the magnitude of the loss was also driven by social awareness.

With asbestos, one expert observed that a handful of judges opened the floodgates to future claims by developing the "triple trigger" idea, which means that all policies in force from the time of initial exposure through manifestation of illness could apply. This greatly expands access to policies and possible recoveries (International Risk Management Institute, 2017; Sweigart, 2012).

The emergence of social media and information sharing via the internet may mean that risks will emerge quicker, so that the timespan over which claims materialise decreases. The compressed time timescale may make it harder for insurers to pay claims. However, the longer an issue is outstanding, the more chances it has to spiral out of control and attract further losses.

8.2.1.3 Technology

It was noted that regulation tends to lag behind technological change. So where there is rapid technological change, these less regulated innovations could lead to more frequent and more systemic losses.

Moreover, particular technological innovations may change the ways risks materialise. For example, the "man-machine" interface has historically been important in different businesses (e.g. aircraft cockpits), but the more extensive use of computers in ships, manufacturing and banking increases the vulnerability to cyber risks. For example, interfering with faulty cargo sensors on an aircraft could lead to overloading the aircraft, or interfering with the temperature sensors in the air-conditioning system of an internet cloud provider could lead to computers overheating.

8.2.1.4 Economic factors

Economic downturns often have an adverse impact on insurer's bottom lines especially in connection to liability claims. In particular, funds, banks, real estate agents along with their professional advisers may be targeted by claimants seeking compensation for financial losses, and potentially triggering losses on E&O/D&O policies (Baluch, Mutenga and Parsons, 2016).

It was also noted that pricing pressures may influence the risk landscape in the longer run:

- Soft rates can sometimes lead underwriters to accept weaker policy wordings, which may increase exposure to unusual losses.
- Pressure to deliver products cheaply can increase the frequency of losses^{vi}.

^{vi} For example, in relation to Chinese toy manufacturers using lead paint, S. Prakash Sethi, a professor at Baruch College, part of the City

- Depressed income caused by a recession may result in the lack of investments in appropriate equipment which could then affect large infrastructure or industrial plants negatively.

8.2.1.5 Timing and latency

How obvious a fault or defect is and how quickly it can be identified it is critical in mitigating losses. If the hazard is detected earlier, fewer parties will be exposed and the overall loss could be lower. The longer it takes to identify a fault, the more time the product with the undetected problem could be sold and used, and the greater the potential damage. It was noted that this depends on the product and the industry. For example, the food industry might have a complex supply chain, but it is usually reasonably apparent if there is a product or systemic fault (although see the discussion relating to the 2011 German e-coli outbreak below), whereas in construction it is harder to detect a fault and determine whether a loss might be systemic.

8.2.2 Risk mitigation

There are a number of mitigating factors mentioned that can control and limit risks.

8.2.2.1 Regulation

Regulation includes what is specified as well as the adaption and enforcement of regulations. Regulation provides a level playing field for insurers and can also reduce the likelihood of an event happening. In more regulated industries, once an event happens, policy frameworks are reactively and frequently brought in to mitigate future occurrence. For example, after the “New England Compounding Center” meningitis outbreak regulations changed to supervise pharmacies’ repackaging of pharmaceuticals (Upton, 2013). After the Lac Mégantic derailment regulations were announced to reduce the flammable nature of oil and gas when undergoing transport by using chemicals (Transport Canada, 2016).

A highly regulated environment was seen to reduce the frequency of liability events, which in turn encourages insurance. In the absence of regulations and the understanding of risks, it is more challenging for insurers to operate.

Risk management encouraged by regulatory frameworks may moderate the severity of an event, or in certain

cases may prevent it altogether. However, the pay-out for an event that happens in a highly regulated environment is likely to be far greater than in less regulated environments. It was also believed that developed countries usually have more advanced legal liability regimes.

8.2.2.2 Jurisdiction

As above, jurisdiction tends to correlate with regulation. Developed countries also tend to have parties who are more highly insured and have better risk prevention, whereas developing nations are relatively underinsured (Lloyd’s, 2012). The corollary is that the damages paid in developing countries for comparable harm are less than in developed countries, Bhopal being an example of an event that would have created greater losses if it had happened in the developed world.

8.2.2.3 Risk management

Risk management varies by industry and also across the same industry based on risk culture and risk maturity. There is also a perceived correlation between high-hazard industries (industries in which there is not a voluntary assumption of risk), and industries that have a low appetite for risk and good risk management.

8.2.2.4 Best practice

Best practice is another risk mitigation implementation and it is also more a function of industry than a country. Best practice is usually defined within an industry, frequently one where there are international standards.

8.2.2.5 Product recall/traceability

The ability to track a faulty product and recall it helps to mitigate the losses. This is what restricted the potential product liability in the Sudan 1 red dye case (BBC News, 2005), where a potentially carcinogenic red dye was supplied by a manufacturer in India and was then found incorporated in many other products e.g. Worcestershire sauce, which itself is used in many other products. The issue was spotted and most products recalled before being purchased and adversely affecting consumers. However, where the fault is not obvious or not detected, or causes more long-term or latent harm, as in the German *E-coli* outbreak in 2011, then recall and batching are less effective. Traceability also varies by industry (e.g. construction components tend to be less traceable whereas, for example, food and aviation components have greater traceability). It was also noted that product recalls minimise product liability but potentially damage reputation.

University of New York, who has acted as an independent monitor of working conditions in Mattel’s factories for the past 10 years, said: “There is something to be said about the pressure that American and European and multinational companies put on Chinese companies to supply cheap products. The operating margins are razor thin, so you really should not be surprised that there is pressure to cut corners.” (The New York Times, 2007).

8.2.2.6 Policy wordings/aggregate limits

An effective limit control mechanism and precise policy wordings can play a significant role in terms of reducing the spread and size of correlated losses in casualty. In addition, endorsing policies that cannot be readily placed can lead to claims arising from liabilities not contemplated by the underwriter.

8.2.3 Distribution of liability

There are a few key factors that may influence how liabilities are distributed among the potential culpable parties. In addition to evolving regulations, there are reputational issues that may influence who pays, and also geographical factors (e.g. different behavioural, cultural trends and different regulatory regimes within different jurisdictions).

Where the losses are likely to lie in the supply and distribution chain they may be influenced by several factors

- A party's position and relative fault in the supply and distribution chain
- The jurisdiction of parties
- The sizes of the parties vis-a-vis the size of the loss
- Distribution between the individual parties
- Distribution between single/systemic events
- Distribution of losses between multiple parties

These are described in the following sections.

8.2.3.1 A party's position and relative fault in the supply and distribution chain

Whether a party is a manufacturer, wholesaler, retailer or adviser it has an impact on the likelihood of their bearing the loss (see Figure 18, p27 and Figure 19, p27).

In product-related cases, the first point of call is usually the retailer, though the retailer may seek to include the manufacturer, who usually is responsible for the fault, particularly if it has the ability to pay. In the UK for instance, the Sale of Goods Act requires retailers to sell products of merchantable quality and free of defects.

Where there is a clear manufacturer's fault, it will be hard for the manufacturer to deny the liability. However, if the manufacturer is bankrupt, outside the jurisdiction or has minimal insurance, the loss may be borne by other parties. There is also a distribution between component, ingredient and finished product manufacturers. The ability to pass liability through the chain of supply will be determined by how easy it is to isolate the precise cause of the loss. It may be more problematic to establish the cause of loss where ingredients and components cannot be extracted from the finished product.

8.2.3.2 The jurisdiction of parties

If some parties are outside a jurisdiction where an event occurs, and beyond the reach of the courts in that jurisdiction, liability may shift to other parties, such as importing wholesalers. In addition, the potential for losses may be greater for a foreign national from one country doing business in another country.

8.2.3.3 The sizes of the parties vis-a-vis the size of the loss

There is a perceived correlation between the size of companies and liability. On the one hand, a larger player has greater leverage to pass liability onto a smaller player through a contract and is usually able to do more risk management to reduce the likelihood or magnitude of a loss event. On the other hand, a large player may attract more claims or be expected to pay more due to "deeper pockets", and the court may be inclined to find the larger party responsible rather than leave a plaintiff uncompensated (see Figure 27, p39) for the earlier discussion on distribution of component losses between parties for illustrative data). The new rules of proportionality that came into force in the UK in 1999 aimed to provide a more level playing field between larger and smaller companies in the context of litigation.

8.2.3.4 Distribution between the individual parties

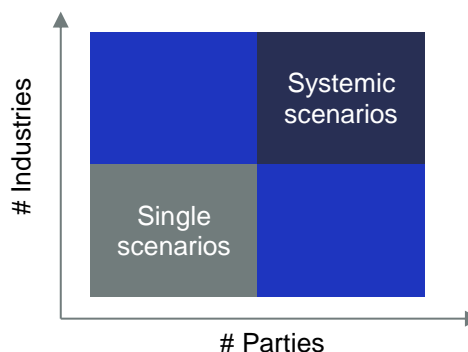
It has been suggested that one or two parties tend to bear the majority of the losses. In the historical data, in 96.4% of the cases, three or fewer parties bear 80% or more of the loss. This is borne out in the historical data.

8.2.3.5 Distribution between single/systemic events

Systemic events were thought to be rarer than single events. The definition of a systemic event used in this report requires both a large number of industries to be affected, and a large number of implicated parties in some (or all) industries.

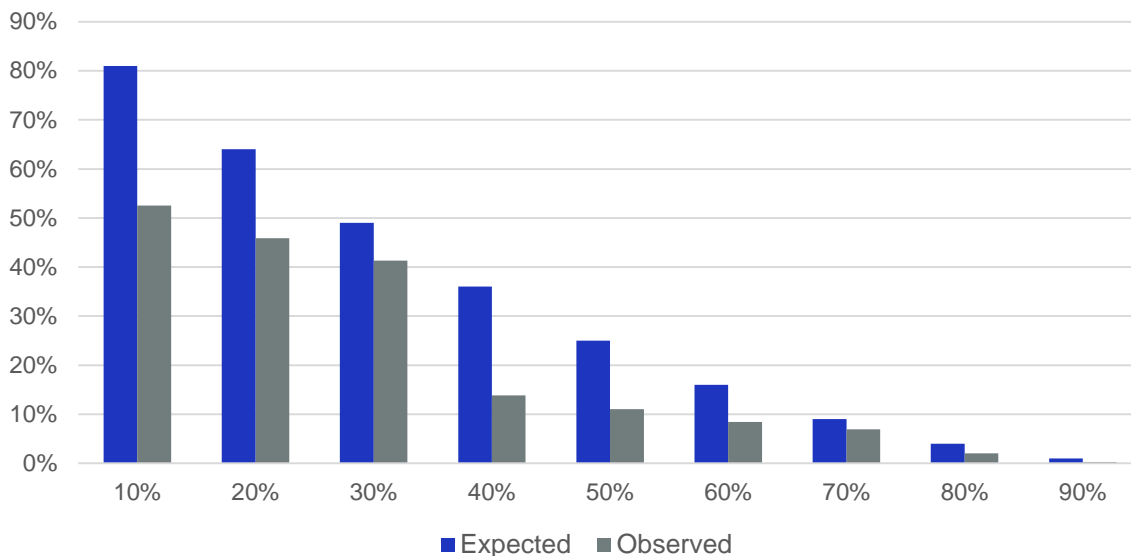
In Figure 25, the proportion of historical events falling into the "Systemic" quadrant is computed.

Figure 25: Distribution of single/systemic events



Specifically, based on data, Figure 26 plots the observed proportions of parties and industries in excess of a given percentile compared to the expected pattern if they were evenly distributed - i.e. systemic events are not special and happen as often as other events (relative to the size of their quadrants)^{vii}. Charting these below, we see a clear difference in that systemic events are rarer than under the “Expected” hypothesis:

Figure 26: Expected and observed losses



For example, the 50% value on the x-axis is interpreted as the events that exceed the median on both metrics, number of industries and number of parties per industry: for all events where both a larger than median number of implicated parties per industry and a larger than median number of industries are observed, the expected proportion of all events under an even distribution would be 25%. The observed proportion is lower at 12.5%, much lower than an even distribution.

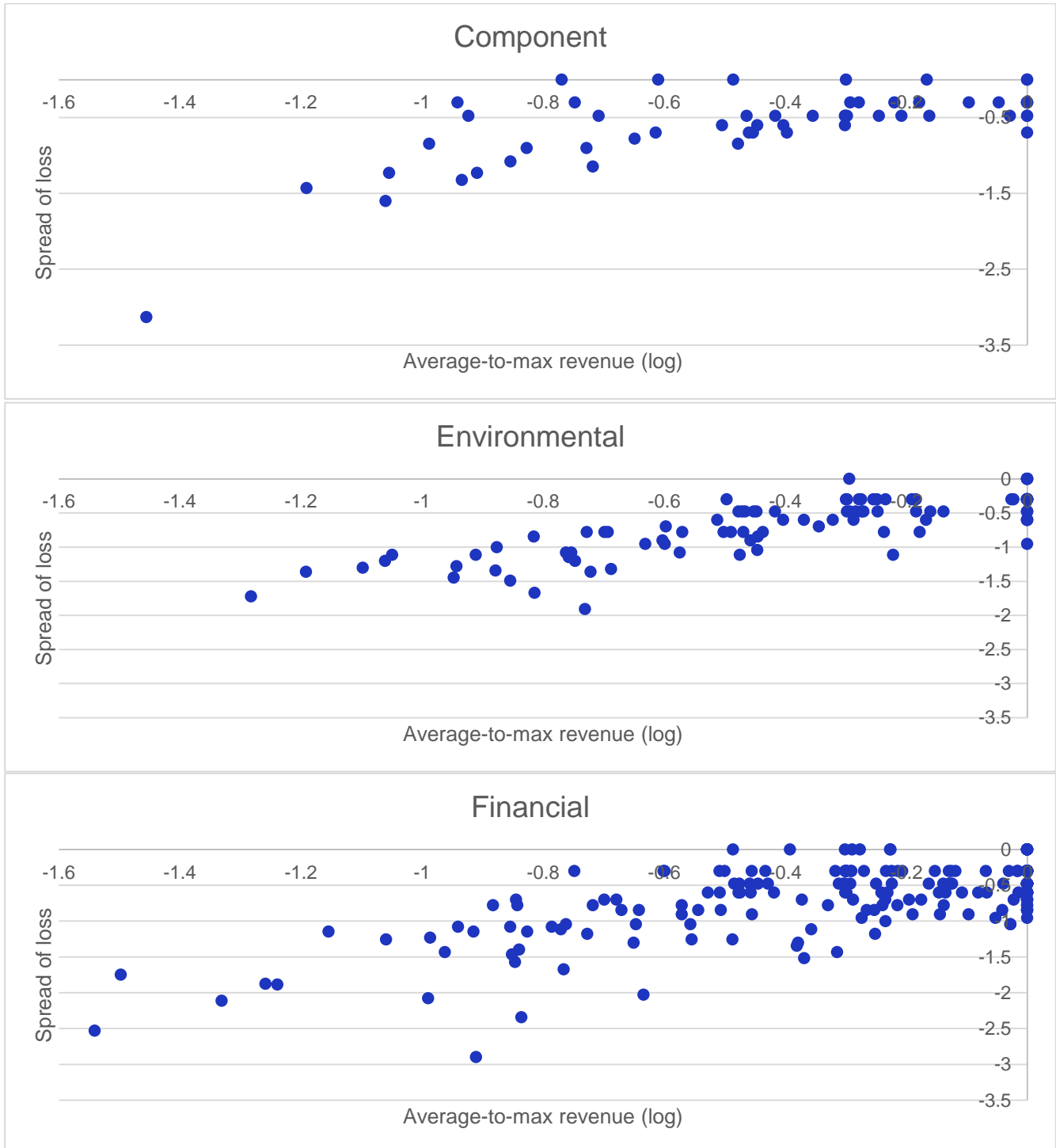
^{vii} Technically speaking, the concept used here is a copula, and the chart is effectively looking at successive values of the copula along the 45-degree line. The chart shows that the dependence pattern has a heavy-tailed behaviour and a Pareto power law with exponent 1.5 seems to capture the dynamics.

8.2.3.6 Distribution of losses between multiple parties

The historical data was also examined for certain events with multiple implicated parties to see if the presence of one or a few larger parties tends to spread the loss so that, for example, the larger parties are bearing more of the loss. In particular, experts observed that where there is a large corporate in a loss scenario, the large corporate could face a larger share of the claim, especially when the loss exceeds the capacity of the

smaller players. Some also observed that in certain industries - e.g. pharmaceuticals, oil and gas, banking - the corporate may be willing to assume liability for reputational reasons, or those reputational issues may make the courts more likely to find the large corporate to be liable. Conversely, it was also observed that a large corporate could use its bargaining power to get smaller players to assume liability for losses.

Figure 27: Correlation of losses



1. The average-to-max ratio of revenues of players implicated for a given loss event. If the ratio is small, then there is a large corporate relative to the other players. The larger the value, the more homogeneous the players are in terms of their revenues.
2. The spread of losses through the supply chain. Essentially, this is the average share of the loss for all industries implicated in a loss event. The lower this is the more losses are shared throughout the supply chain. If this value is high, then losses are relatively concentrated.

If both values are low, then the existence of a big player coincides with a bigger spread of losses in the supply chain. If both values are high, then a homogeneous set of players coincides with a concentrated loss.

A positive correlation between both values would corroborate expert observations, and this is indeed the case. In particular a positive correlation was found, specially with respect to the component/ingredient shape discussed in this section (“component”); the finished product shape with respect to events involving financial institutions (“financial”), discussed in Section 4.1 (see *p16*); and the infrastructure/operational shape with respect to events having an environmental impact (‘environmental’) discussed in Section 4.2 (see *p19*). This is demonstrated by Figure 27, where the above metrics are charted one against the other on a log-scale^{viii}: By means of comparison to other types of shapes, this correlation is still detectable but weaker for other “finished product” type scenarios, and very weak for “infrastructure”.

^{viii} The log-scale is used in order to magnify observations where both dispersion of losses and average-to-max ratio are small.

8.3 Occurrence probabilities

Occurrence probabilities are the mathematical vehicle to describe how often in a given period of time a realisation from a particular shape occurs. The shapes described tend to have different occurrence probabilities associated with them.

8.3.1 Stationary probabilities

Stationary probabilities are relatively stable over time. Of course, the precise meaning of this is subject to convention, but typically human error rates are seen as a relatively stable quantity, although the degree and effectiveness of risk management and other mitigation may vary between industries and jurisdictions.

8.3.2 Non-stationary probabilities

Non-stationarity is present when the probability of occurrence depends in a significant fashion on factors that are time-dependent.

For example, whereas there are currently no truly systemic cyber-loss scenarios on historical record, several studies have suggested that their occurrence is now a possibility^{ix}. Similarly, it may be argued that certain scenarios that have materialised in the past would not repeat as a loss scenario because the underlying mechanics would now be prevented by a better understanding of the hazard, or a different legal landscape.

8.4 Technical implementation of the concept

8.4.1 Process architecture

This section presents an overview of the workflow as it was implemented during this project. The first step was to translate expert knowledge, historical loss data and supply chain data into parameterised forms.

The first step consists in capturing the shapes and can be divided in:

- Determining the set of possible starting nodes.
- Understanding if the shape model scenarios that implicate suppliers and/or customers.
- Exploring how far-reaching the event is (i.e. if it extends to first-, second-, third-tier suppliers).

The second step consists in the parameterisation of shapes and it includes:

- Specifying liability-related variables.
- Specifying dependence and/or correlation between these variables as well as between variables and the structure of the supply chain as per step one above.

These initial parameters reflect a plausible set of assumptions, which over time will continue to evolve in light of further input, changes in the socio-economic environment and to reflect a better understanding of risk.

^{ix} For example the Sybil logic bomb cyber catastrophe scenario (Centre for Risks Studies, 2014)

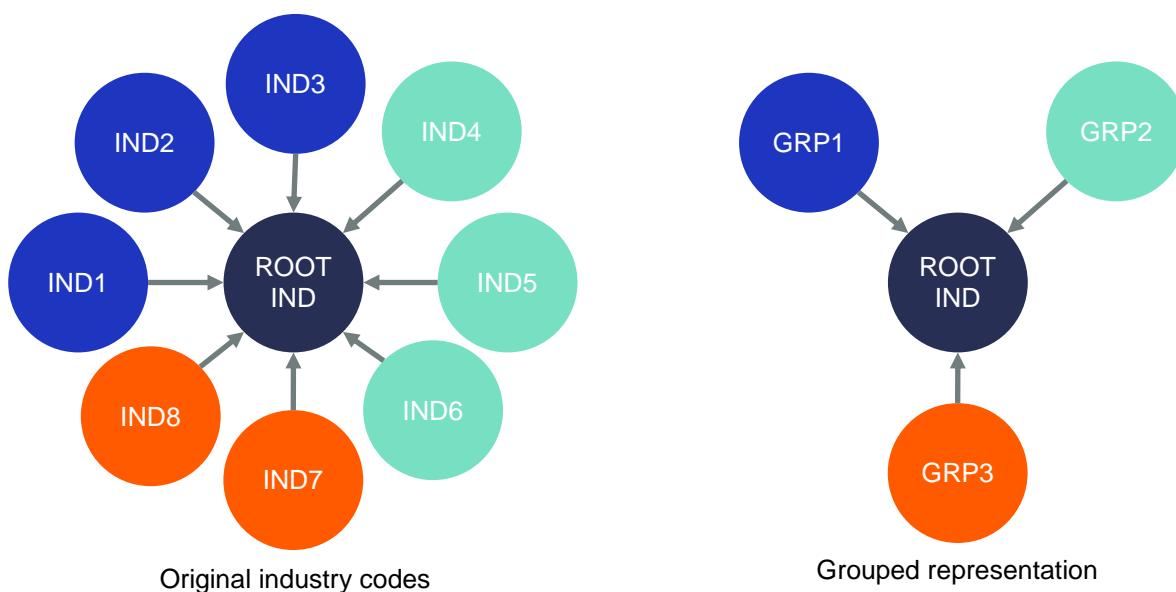
8.4.2 Hierarchical representation of shapes

The first step in the process of deriving loss scenarios is capturing the shape in order to fix the set of industries that are part of a particular shape, as well as the footprint of the supply chain (its extent and depth).

A crucial question is how to represent uncertainty in the structure of the supply chain. One way to achieve this is to relate node groups by means of a hierarchical tree that serves to capture the connections between groups.

To start off, node groups are a collection of industries with same properties from a modelling point of view. This occurs either because two industries actually have the same loss characteristic or there is no meaningful information available for further differentiation^x. A root node, which may be chosen flexibly depending on the risk scenario, is usually the set of industries where a particular risk scenario may emanate from (e.g. the manufacturer in the “Finished product” shape). Schematically, original and grouped representations can be represented as follows:

Figure 28: Representation examples



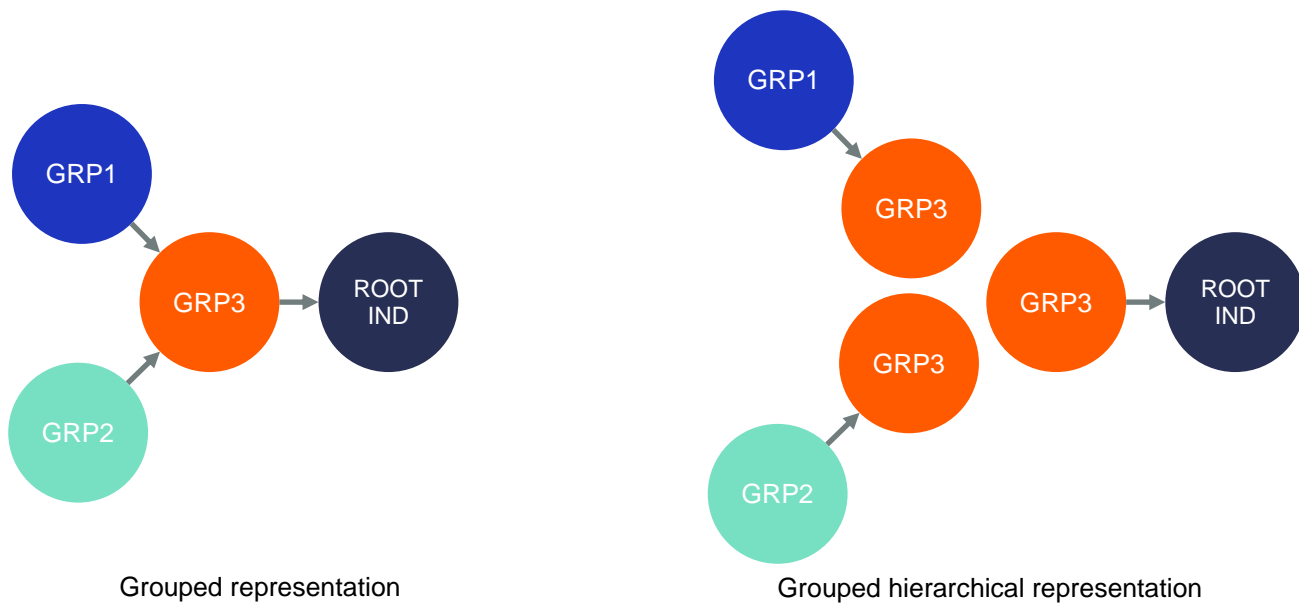
Above, the “root Industry” (ROOT IND) is supplied by industries 1-8 (the “Corporate” shape is similar to this). These industries are then grouped - for example industries 1-3 form group 1 (GRP1). These groups form the skeleton for all further parameterisation, such as the shares of loss attributable to each. In the latter example, these shares are specified either as deterministic or stochastic variables. Groups may appear several times in a given shape, as would be the case with professional advisory firms that may be implicated at several points in the same supply chain.

Nodes are then related by supplier-to-customer and/or customer-to-supplier relationships^{xi} as shown below for a situation when industries from groups 1 and 2 supply industries in group 3, which in turn supply the root node industries.

^x In statistics, this is often referred to as a “uniform prior”.

^{xi} In terms of the hierarchical tree, these are the parent-child relationships.

Figure 29: Representation examples



The representation is hierarchical as in this instance GRP3 supplies into ROOT IND, and in turn GRP1 and GRP2 supply GRP3.

These supply-chain relationships are also parameterised. For example, links may or may not be associated with trade strength data, depending on whether doing so makes sense for the shape at hand. With the corporate shape for example there is no association to trade as the amount of trade between relevant professional advisory services and the imploding company is not expected to impact the scenario outcome. On the other side, trade data can be used to effectively identify supply chains that are used to manufacture certain goods or provide certain services. However, in this context, the reader is reminded that the outcomes of this process are in major part determined by pre-selecting the industries that make up the shape.

It is important to note that in terms of the underlying trade map, there are situations when the link is indirect within the economic network. In other words, links may be direct or indirect^{xii} in terms of the trade data, and part of the parameters capture the number of steps (or maximum number of steps to go). Similarly, deterministic or stochastic rules may be used to decide which links are followed or not. A typical case would be a scenario where a faulty component causes liability to multiple finished product manufacturers versus just one.

8.4.3 Sampling scenarios

Once shapes are parameterised, it is then possible to sample concrete realisations to create scenarios at

^{xii} For example, retailers can be supplied directly by the manufacturer, or indirectly through a wholesaler.

economy-level (i.e. making no reference to any insured portfolio) by:

1. Sampling a set of concrete industry codes from abstract representation.
2. Sampling a concrete realisation of event parameters from abstract representation.

Finally, one can then calculate losses for a given insured portfolio. The vehicle for this is the loss-allocation methodology that is part of the methodology outlined in the previous paper (Lloyd's, 2015). For convenience, the essence of this approach is reiterated in the next two sections.

8.4.4 Methodological limitations

From a capital perspective, insurers and regulatory frameworks are usually concerned about assessing tail risks over the short- to medium-term - normally one year. However, it is not uncommon for liability claims to take months or years from notification to settlement. This long-tail nature means that accurate reserving may play a more important role relative to premium risk than, for example, in property insurance, as the relevant information about property losses often materialises more quickly. For reserving, deterministic scenario modelling may be more suitable, because an event that has already occurred is modelled. The solution advocated here is to make use of deterministic risk scenario modelling, presented in the paper "Designing liability scenarios", which complements outputs from the stochastic model. In particular, deterministic scenarios can be blended with outputs from the stochastic model, for example by using the former to model tail risk (for capital setting purposes) and the latter to cover the bulk of the distribution (more relevant for rating).

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