Part I
Identification and Analysis of Catastrophic Risk

1 Catastrophe and Risk

1.1 INTRODUCTION

Risk, which we define as the uncertainty surrounding the outcome of an event, is an integral and inevitable part of business. Companies and governments operating in the complex economic environment of the 21st century must contend with a broad range of risks. Some do so in an ad hoc or reactive fashion, responding to risks as they appear, while others are proactive, planning in advance the risks that they wish to assume and how they can best manage them. Since it has become clear over the past few years that risk can be financially damaging when neglected, anecdotal and empirical evidence suggests that institutions increasingly opt for formalized processes to manage uncertainties that can lead to losses.

Risk can be classified in a number of ways and, though we do not intend to present a detailed taxonomy of risk, a brief overview is useful in order to frame our discussion. To begin, risk can be divided broadly into financial risk and operating risk. Financial risk is the risk of loss arising from the movement of a market or performance of a counterparty, and can be segregated into market risk (the risk of loss due to movement in market references, such as interest rates, stock prices, or currency rates), liquidity risk (the risk of loss due to an inability to obtain unsecured funding or sell assets in order to make payments), and credit risk (the risk of loss due to non-performance by a counterparty on its contractual obligations). A rise in funding costs, an inability to sell financial assets at carrying value, or the default by a counterparty on a loan are examples of financial risks. Operating risk, in contrast, is the risk of loss arising from events that impact non-financial business inputs, outputs, and processes. Lack of electricity needed to power assembly lines, collapse of a computer network, disruptions in the sourcing of raw materials, or misdirection of payments or orders are examples of operating risks.

Risk can also be classified in pure or speculative form. Pure risk is any exposure that results either in a loss or in no loss, but can never generate a gain; speculative risk is an exposure that can result in a gain, a loss, or no loss. In general, operating risks are often pure risks (e.g., if an assembly line fails to function as expected a loss results, and if it functions as it should no loss occurs), while financial risks are often speculative risks (e.g., if interest rates rise the cost of funding rises and a loss occurs, if interest rates decline the cost of funding declines and a saving, or ‘gain,’ results).

Risk can also be classified by frequency and severity. Though the specter of risk is present in virtually all business activities, the frequency of occurrence can vary widely. Some exposures can create losses (or gains) every day, week, or month. For instance, currency rates move every day, and a firm with unhedged foreign exchange risk that revalues its operations to daily closing rates will experience a loss (or gain) each business day. In general, however, these frequent losses (or gains) are likely to be relatively modest in size, as the foreign exchange market can only move by a certain amount on a given business day.[1] The same is true for many other

[1] In extremely rare circumstances a financial event such as a devaluation might cause a currency rate to move by a large amount; this is quite exceptional, however, and not part of the normal pattern of markets.

financial risks, which are collectively considered to be high frequency/low severity risks – that is, a loss or gain may occur every day, but the absolute size is almost certain to be quite small.

Other exposures create losses (or gains) much less frequently, perhaps every few years or decades. For example, an energy company operating a natural gas-fired generator is exposed to the risk of mechanical failure, which might cause the generator to cease producing power. Given the design of the equipment such a shut down is not expected to occur, but if it does happen the financial consequences from interrupted business revenues may be significant. Similarly, a violent tornado may strike an agricultural area and destroy an agricultural cooperative's crops; the tornado is not expected to occur very often, but if it does, the crop damage may be substantial. Or, a very large systemic liquidity crisis may occur in the banking sector as a result of a unique confluence of micro- and macro-economic events; again, although the event is not expected to happen very frequently, it may cause substantial economic damage. These types of natural or man-made events, often termed catastrophic, or disaster, risks, are considered to be low frequency/high severity risks – they do not occur very often, but they have the potential of creating very large losses. The focus of our discussion in this book is on such catastrophic risks.

The basic classification of risk by type, result, and frequency/severity is summarized in Figure 1.1.

Catastrophe risk is a broad topic that must be viewed holistically, as it can impact many facets of society – human, social, political, cultural, scientific, and economic. The very breadth of its impact means a specialist focus on the individual components is generally necessary. In fact, this book is centered specifically on the financial/economic impact of catastrophic risks, and how exposures can be analyzed and managed in order to minimize losses. While the management of all financial and operating risks is critical to continued prosperity in the private and public sectors, we shall not address the high frequency/low severity exposures that affect daily business activities; these are beyond our purview and are treated in many other works. Neither shall we attempt to address the social, cultural, or scientific issues of catastrophes, or those surrounding crisis management and disaster recovery. Again, these are vital issues, but well beyond our scope. In the balance of this chapter we consider the nature of catastrophe and its potential scope of impact; we also introduce the concept of catastrophe risk in the conventional risk management framework, and provide an overview of the structure of the text.

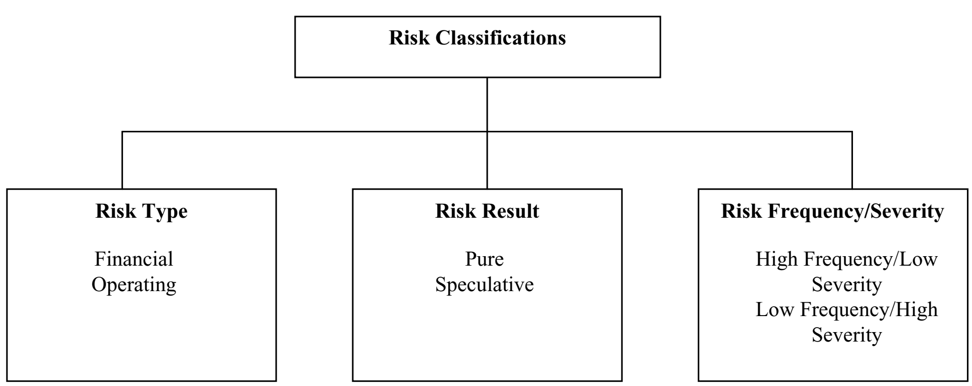

Figure 1.1 Basic risk classifications

1.2 THE NATURE OF CATASTROPHE

1.2.1 A definition

Catastrophe does not lend itself to a simple, universal definition. While we have mentioned that a catastrophic event is a low frequency/high severity risk, it may be sudden or prolonged, and natural or man-made; it may affect valuable financial/physical assets in a densely populated city, or it may impact a desolate and unpopulated region; and, it may be measured by arbitrary guidelines or very precise metrics. Despite room for interpretation we shall develop certain definitions and concepts that provide us with the necessary tools to evaluate catastrophe and catastrophe risk (with some caution to the reader that other alternatives and extensions may be perfectly acceptable).

For our purposes we define a catastrophe as a low probability natural or man-made event that creates shocks to existing social, economic, and/or environmental frameworks, and has the potential of producing very significant human and/or financial losses. Though a catastrophe is traditionally viewed as a single large event that causes sudden change – such as an earthquake or terrorist attack – we can expand the definition to include instances where a gradual accumulation of many small incidents, perhaps precipitated by the same catalyst, leads to the same scale of damage/losses; such events may not actually be recognized as catastrophes until a long period of time has passed and many losses have accumulated.[2]

Although the potential for large losses exists, a catastrophic event does not always lead to losses. While we are primarily concerned with events that might produce losses and considering what can be done to mitigate or minimize them, we would be remiss in excluding events that occur without creating losses. Accordingly, a large earthquake striking in an unpopulated region of the Aleutian Islands and a similar earthquake striking in the densely populated city-center of Kobe are both catastrophic events.

The catastrophe is the event itself, and not the specific human or financial outcome of the event; this is important because each new event, whether or not it creates social/economic damage, becomes part of the historical data record that is so vital in developing an analytic framework. Naturally, from a pure risk management perspective we are primarily interested in situations that have the potential of creating real event losses.[3]

1.2.2 Frequency

Many types of financial and operating risks appear on a regular basis – so regularly, in fact, that their impact can be estimated with a high degree of accuracy through standardized tools. Automobile accidents, household fires, stock price declines, standard medical procedures, and other non-catastrophic risk events occur every day, and the severity of each individual event is generally quite small. They can be quantified through statistical frameworks and actuarial processes, allowing exposed parties to make cost/benefit decisions with a high degree of confidence.

The same does not necessarily apply to catastrophes. Most catastrophes occur very infrequently, and they may be quite severe. For instance, although some 700 significant natural

[2] Some exposures with very long ‘tails’ or duration may be subject to changes in regulations or legal terms that create large-scale liabilities and losses that only become evident over time (e.g., asbestos, environmental disposal).

[3] We can define an event loss as the sum of all individual losses for a single catastrophic occurrence; for example, an earthquake is considered to be a single catastrophic occurrence, while the sum of the individual losses the earthquake creates for 1000 (or 10 000, or 50 000) homeowners becomes the event loss.

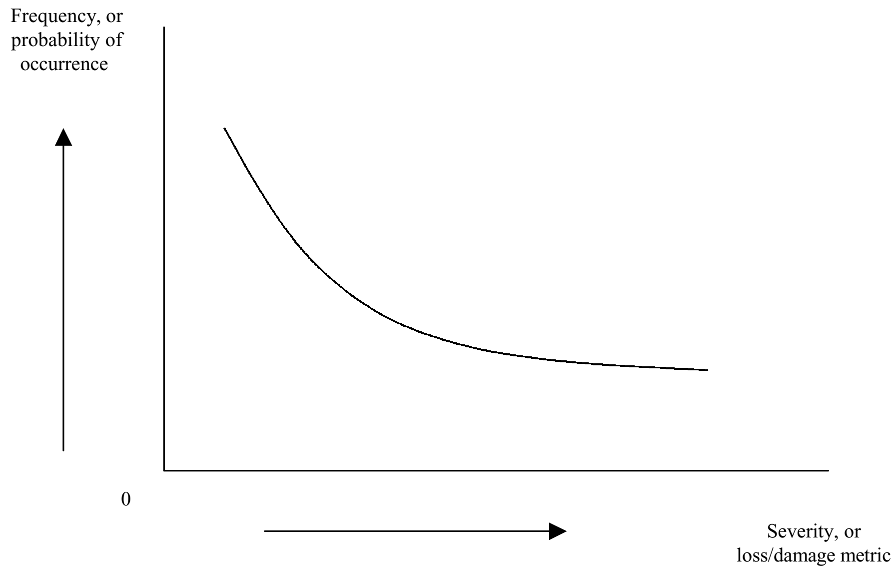

Figure 1.2 Frequency and severity

disasters occur in an average year, this figure is quite small given the number of vulnerable areas around the world; one of these 700 events may only appear in a given location once every ten, hundred, or five hundred years – and sometimes even longer. The tools and rich history of past events that are used to evaluate frequently occurring risks are not available to help in the quantification process. These differences, as we shall note later, make financial modeling, decision-making, and ongoing management more challenging. Despite this relative lack of frequency, some types of catastrophes recur, meaning that they can be anticipated – though not predicted. In the short term catastrophes are non-routine, often appearing as random events; in the very long term, however, certain classes are routine.

The probability that a particular type of catastrophe will occur is generally expressed as an annual occurrence frequency, e.g., there may be a 0.01% probability of an 8.0 magnitude earthquake occurring in City XYZ in a given year. This can be depicted in graph form, as in Figure 1.2, where frequency is conveyed as a probability of occurrence and severity as a metric of loss or damage (e.g., dollar losses, magnitude, intensity). Events that occur very frequently and have low severity outcomes dominate the left-hand portion of the curve; those that appear infrequently and have higher severity outcomes comprise the right-hand portion of the curve; the two relationships are depicted in Figure 1.3.[4]

An associated frequency measure is the recurrence interval (or return period), or the average time within which an event equal to, or greater than, a designated severity occurs; this is simply the time-independent inverse of the occurrence frequency, i.e., the recurrence interval of the 8.0 earthquake in City XYZ is 100 years (1/100 years = 0.01%). Occurrence frequency and return period are typically held constant from year to year in analytic frameworks, apart from any condition changes owing to man-made influences. A related concept is the non-encounter

[4] Note that there is no single *ex ante* ‘dividing point’ between non-catastrophic and catastrophic events; the classification on the curve is for illustrative purposes, and depends on individual circumstances.

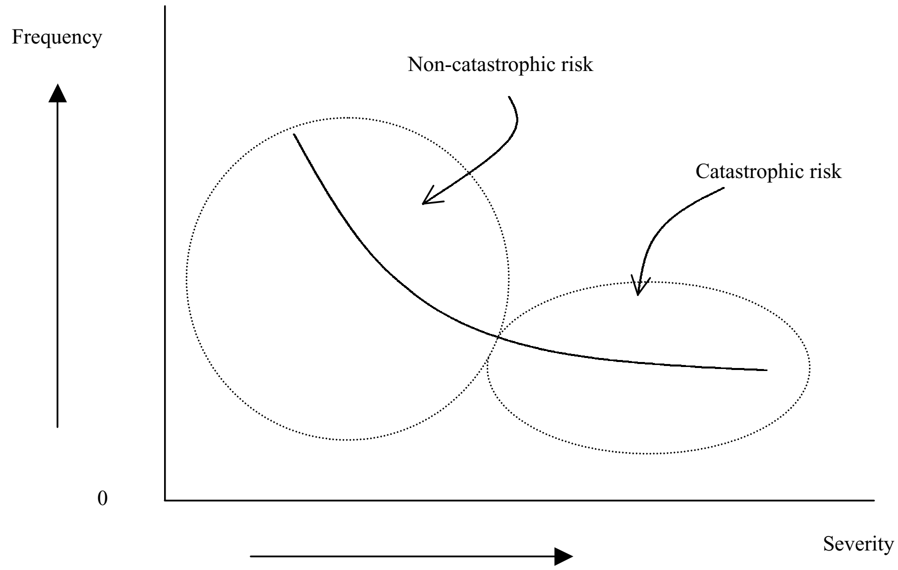

Figure 1.3 Catastrophic and non-catastrophic frequency and severity

probability, or the probability that no event greater than, or equal to, a given magnitude will occur over a particular period, i.e., there is a 99.9% annual non-encounter probability of an 8.0+ earthquake striking in City XYZ. All three measures of frequency are widely used in catastrophe risk management, and we shall revisit them throughout the book.

Knowing that catastrophes occur infrequently is an important consideration when evaluating the potential for losses, as a large magnitude event that occurs only rarely must be managed differently from a small magnitude event appearing regularly. It is not sufficient, of course, to say that catastrophes occur infrequently; within this broad classification we can divide frequency even further, into non-repetitive, irregular, regular, and seasonal events (further granularity is possible, but this categorization is detailed enough for our purposes).

- *Non-repetitive catastrophe*: a disaster that occurs only once in a particular area and can never be repeated in the same location to yield the same results. Examples include the collapse of a dam (which forever changes the channel, floodplain, and discharge dynamics above and below the dam), a massive landslide from a mountain slope (which permanently alters the landscape and potential for a repeat event), or a terrorist bombing (which obliterates a landmark structure in a particular location permanently). It is important to note that non-repetitive catastrophes can recur, but always in different locations and/or under different circumstances (e.g., another dam can collapse, another building can be bombed); the time and location of future events remain unknown.
- *Irregular catastrophe*: a disaster that does not appear with any degree of statistical regularity, but which can occur repeatedly in a general location or marketplace, though time and specific location are generally unknown. Examples of irregular catastrophe include a tsunami generated by an earthquake, or a very large stock market collapse.
- *Regular catastrophe*: a disaster that is characterized by the regular, if sometimes very long and gradual, accumulation of forces that lead to the triggering of an event. Though the

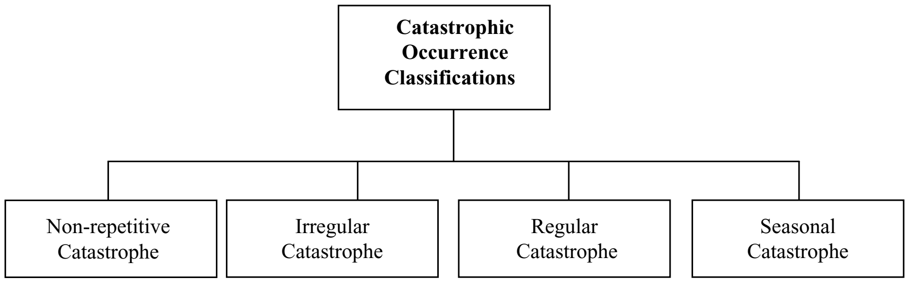

Figure 1.4 Catastrophic occurrence classifications

pattern of buildup occurs on a regular basis and can be accommodated within a statistical framework, the precise timing of event occurrence remains unknown. Examples of regular catastrophe include an earthquake on a known fault line or a volcanic eruption from an active volcano.

- *Seasonal catastrophe*: a disaster that has the potential of occurring on a regular basis in a general location during a given time period; while this helps limit the time and space of occurrence, the precise location, severity, and moment of occurrence remain unknown. Examples include hurricanes, extra-tropical cyclones, floods, and droughts, all of which can occur in particular areas during specific seasons.

Catastrophes that feature a dimension of repetition, such as regular or seasonal events, can be described by statistical distributions, which allows for better estimates of severity and frequency. Those that are non-repetitive or irregular are more challenging to quantify. We shall consider this point at greater length in Chapter 4. Figure 1.4 summarizes the classifications noted above.

Some observers have noted that the frequency of disasters appears to have increased over the past few decades. In fact, there is little scientific evidence to support such a claim: the frequency of disasters such as earthquakes, flooding, tornadoes, extra-tropical cyclones, industrial contamination, or terrorism does not appear to be accelerating, nor is it necessarily expected to. While global warming and changes in the hydrological cycle have alternately increased and decreased certain hazards that have the potential of creating disasters (e.g., spring flooding and winter storms, respectively), and though certain man-made events appear to be on the rise as a result of geopolitical tensions (e.g., large-scale terrorist-related activities), the incidence of disasters has not actually increased. In fact, growing media coverage and larger damages may be contributing to the perception of increased frequency.

1.2.3 Vulnerability

As we explore dimensions of low frequency/high severity risks, we want to consider the element of the topic that is most important to our theme – the management of losses. In particular, we consider the concept of economic vulnerabilities. From a risk management perspective, we are interested in understanding the interaction between catastrophe and vulnerabilities in order to determine the potential for losses of a given size, and ways of minimizing such losses.

A vulnerability exists when humans and/or infrastructure are present and 'at risk' when a catastrophe strikes, or has the potential of striking. Vulnerabilities represent the potential for losses from casualty, damage, destruction, and/or business interruption. When vulnerabilities are present and a catastrophe occurs, some amount of losses will result; when no vulnerabilities exist, no losses can occur. Thus, the unpopulated region of the Aleutians has no vulnerabilities – when the earthquake strikes, no losses will ensue, as human life and infrastructure are not exposed to the risk. But the densely populated center of Kobe is highly vulnerable to loss; when the earthquake hits, as it did in January 1995, the combination of the actual catastrophe and the vulnerability generates losses. The existence of vulnerability can be estimated without precise knowledge of risk levels, but the size of a loss cannot be quantified without also estimating the strength of a particular catastrophic event.

Vulnerability is a dynamic variable. As society grows and changes, new technologies are developed, new construction techniques are introduced, and demographic and migration patterns fluctuate, associated vulnerabilities change – sometimes dramatically. In general, vulnerability increases as the world's population grows and the value of assets and infrastructure multiply (even if technical/engineering advances can help reduce the amount of damage that occurs); though the frequency of catastrophe may not increase, losses continue to expand as greater wealth is built.

In fact, population growth, which tends to generate asset and wealth expansion, is a key driver of vulnerability growth. Exponential population growth over the past 2000 years means that vulnerabilities have increased rapidly and continue to expand (e.g., global population of 3b in 1960 is predicted to reach 7b by 2012); an estimated current annual growth rate of approximately 1.4% leads to population doubling time of 50 years, meaning ever-larger human and financial exposure to catastrophic risk.[5] Many areas that are exposed to a range of perils – such as the coastal USA, Japan, Taiwan, France, China, and Mexico – have grown rapidly over the past century and are expected to grow at a similar pace for the foreseeable future.

In some instances vulnerabilities can be controlled and managed by limiting participation or development in at-risk areas or introducing mitigation or loss financing techniques. In other cases they cannot be controlled as there is simply no alternative but to permit development; this is particularly true in nations that face limited regional development alternatives. Interestingly, in some instances individuals and societies willingly increase their vulnerabilities by developing at-risk areas. This tends to occur primarily in wealthier nations, where development opportunities in safe or low-risk areas exist, but where it may be regarded as desirable to live and work in a peril-prone region (e.g., a coastal area exposed to hurricanes or flooding, or a mountain area prone to earthquakes and land mass movement). Thus, despite knowledge of risk and vulnerability reduction techniques, political, social, and economic forces foster expansion and development in risky areas. Under this scenario economic progress and free selection dominate scientific knowledge and environmental conditions. Only when a major disaster strikes might such behavior change – though even this is not guaranteed, as legislative efforts may not succeed in banning development, or those impacted may simply choose to return to the status quo (believing, perhaps, that the 'big one' has passed and that they will be safe for the next 10, 50, or 100 years). In some instances exposed parties prefer to deny the threat of the peril, believing that nothing will occur, or that loss control schemes and construction standards will provide necessary protections. These beliefs may increase vulnerability over time, and make any incident that much more devastating. Catastrophe, vulnerability, and loss can therefore be viewed as a combination of cause and effect. One extreme view suggests that humans who

[5] This may be partly offset by the fact that industrialized nations, with greater concentrations of asset wealth, exhibit stable population patterns (though continued expansion in asset accumulation); it is also partly offset by technical/engineering advances.

choose, or are forced, to develop in areas that are exposed to catastrophe, cause losses; the ‘fault’ lies with human development, rather than the event itself. A more moderate view indicates that losses occur because of joint interaction between human motivations and catastrophes. Regardless of perspective or semantics, it is clear that catastrophe exists independent of losses, but the interesting issues of financial management arise when vulnerabilities are introduced. A related point is that vulnerabilities may occasionally be underestimated as a result of the dynamism that characterizes progress and development. This can lead to greater than expected losses in the event of disaster, rendering post-loss financing programs inadequate. Consider, for instance, that prior to the arrival of devastating Hurricane Andrew in Florida in 1992, the single largest loss estimate for a hurricane was $7b; this was based, in part, on previous worst case losses from other disasters,[6] along with some extrapolation on population and asset value growth in sensitive regions. To the surprise of many, Andrew generated $26b in total losses (including $15.5b of insurable losses), multiples of the previous ‘conservative’ loss estimate, because of the force of the event and a general underestimate of the vulnerabilities in the affected region. Not surprisingly, many homeowners, business owners, insurers, and reinsurers were financially unprepared for the losses and experienced financial distress.

Just two years later the California Northridge earthquake struck, causing $40b in total losses ($14b of insurable losses) – again, well in excess of any expectations (had Andrew and Northridge occurred in the same year, the insurance/reinsurance sectors would have faced devastating losses and a very high incidence of insolvency). Similarly, though insurers and reinsurers had actively estimated the potential for economic loss from terrorist activities since the 1970s, few expected an event equal to the magnitude of the 9/11 events: the $90b in direct and indirect losses that resulted from the four airplane strikes was underestimated by any measure.

Gauging vulnerabilities is thus a crucial and complex process – and one that is essential to effective risk management. Fortunately, improvements in modeling techniques, accumulation of historical data points, refinements in the construction of loss distributions, and compilation of more granular information regarding assets and structures has permitted development of better loss estimates. While just a decade ago the world was surprised that a single hurricane could generate $26b of damage, there is now widespread agreement among academics and practitioners involved in disaster management that if Andrew had turned northwards by a mere 30 miles it would have caused damage of $60b to $100b. Similarly, research suggests the possibility that future hurricanes impacting the Northeast USA and Florida could create losses of $20b and $75b, respectively, a California earthquake or continental European windstorm could lead to losses of $50b to $100b, an 8.5 magnitude earthquake in the New Madrid Seismic Zone of the central USA could create $100b of losses, and a repeat of the devastating 1923 Tokyo earthquake in today’s market could lead to losses of $500b to $1t. The US General Accounting Office has compiled insurance industry estimates that suggest a hurricane striking a densely populated area could cost $110b, while a large earthquake could cost over $225b. Modeling firm Risk Management Solutions (RMS) has estimated the 100-year and 250-year return period losses of Florida hurricanes at $30b and $41b, respectively, Southern California earthquakes at $15b and $27b, and US multi-peril events at $59b and $115b. Applied Insurance Research (AIR), another leading modeling firm, has estimated that a repeat in the millennium of the relatively rare New England hurricane of 1938 would cause nearly $30b of damage. The

[6] Reference points included $4.4b from windstorm 87J in the UK in 1987, $5.6b from Hurricane Hugo in the Caribbean in 1989, and $6.9b from Typhoon Mireille in Japan in 1991.

growth of human and economic vulnerability has made these figures seem less unrealistic than they would have seemed only a few years ago.

1.2.4 Measuring severity

Catastrophes are generally measured by physical, social, and economic severity in order to provide an estimate of potential and actual damage. This provides useful information for both analytic assessment and exposure management. Ranking the physical severity of a catastrophe can be a complex undertaking. In some instances the metrics are clear, well established and widely accepted (if based, in some cases, on rather arbitrary thresholds).[7] This is particularly true of natural disasters, which use recognized metrics such as the Richter scale, Shindo scale, and moment magnitude scale (earthquake), Saffir–Simpson scale (hurricane), Fujita scale (tornado), volcanic explosivity intensity (volcano), and so on; we shall consider these measures in the next chapter. In other cases metrics are far less clear, or of limited application to other events; indeed, there may be no established gauge of physical severity. This may apply in the case of both natural and man-made disasters (e.g., a land mass movement, crude oil spill, or bomb explosion may be unique to time and location, it may not be measurable with any degree of precision, or it may provide no meaningful comparative data). Nevertheless, some effort at measuring physical severity is necessary in order to supplement data used in the quantitative process.

Measuring the social/economic severity of a catastrophe is also a complicated task that depends largely on the perspective of the analyst, researcher, or risk manager. Public sector organizations often measure severity based on the number of injuries, casualties, or displaced persons so that they can provide appropriate medical care, aid, or shelter. Companies, insurers, reinsurers, financial institutions, and government authorities responsible for assessing financial losses, settling claims, or providing reimbursements or loans to affected parties gauge severity by tabulating total economic losses. In some instances measuring economic losses can take months or years. Again, the determination of financial severity is an essential element of risk quantification. Without de-emphasizing or reducing the critical importance of the human consequences of physical catastrophes, our discussion will focus primarily on the direct economic implications of such events.

1.3 THE SCOPE OF IMPACT

Expanding on our brief introduction of vulnerability, we know that catastrophic events can generate significant damage. From a social perspective thousands, or tens of thousands, of casualties can devastate a community and a nation, and a state of emergency may be declared as the social framework is temporarily or permanently disrupted. From a financial perspective a disaster can place a tremendous burden on citizens, the private corporate sector, and the public sector, creating financial distress and slowing economic progress for weeks, months, or years.[8]

[7] For instance, in order for a tropical storm to be elevated to tropical cyclone status it must achieve a minimum (arbitrary) wind speed of 74 mph.

[8] Even a relatively moderate catastrophe can have a major impact on a small national economy. Consider, for instance, that Hurricane Gilbert (1988) caused $1b of damage in Jamaica; though modest compared with other instances of regional hurricane damage, it was large relative to the size of the local economy. In fact, the losses were equivalent to 25% of Jamaica's gross domestic product (based primarily on agriculture and tourism); export earnings declined by 15%, the public sector deficit increased by 5 times, and inflation accelerated dramatically.

The long-term economic impact of any catastrophe depends on the size of the direct losses, whether direct losses influence indirect losses and secondary costs, and how well an affected company/country can cope with the losses. For purposes of our discussion we can define direct loss as financial damage to capital assets, indirect loss as business interruption resulting from loss of capital assets (and measured by lost output and earnings), and secondary costs as costs associated with disruption of development plans and increased debt/public sector deficits. While direct and indirect losses can generally be estimated *ex ante* and reconciled *ex post*, secondary losses are much more difficult to ascertain (*ex ante* and *ex post*), since a national economy is a complex system of linkages, some of which may or may not be affected by the onset of a disaster.

The scope of impact is directly related to the severity of the event and the level of vulnerability. As we have noted above, a severe event in an area with little or no vulnerability will not produce social or financial losses of consequence. Similarly, a moderate event in a vulnerable area will have a modest impact, while a severe event in the same area will have a significant impact. This relationship becomes important when we consider various risk management solutions in Part II.

The depth and breadth of economic and social impact is dynamic, and driven largely by human progress (development and vulnerability) and action (mitigation and management). Let us assume that a region is exposed to catastrophic events that range in severity from an arbitrary 1 (weak) to 3 (strong), and that we can apply to this the scope of vulnerability to determine financial losses. Our result is a matrix of economic losses where the impact is driven primarily by the level of vulnerability – a direct function of human progress and action. Assuming complete economic loss of vulnerable assets if an event occurs and a linear relationship between severity and loss, we can consider several scenarios to illustrate our point. If vulnerability is equal to 100 and an event of force 1 occurs, the resulting economic loss is 100; if a severe event 3 occurs, the loss rises to 300. Thus, the catastrophe can cause a loss ranging from 100 to 300; nothing worse can happen. Assume next that the state continues to develop its community and infrastructure so that the value of local assets increases from 100 to 300; in developing such assets it does not alter its actions (i.e., it does not change its mitigation or management policies). If a catastrophe strikes, the economic loss will now range from 300 to 900 – significantly greater than in the previous state of development, despite the fact that the actual severity of the disaster remains bounded. It is simple to extend the example by reflecting increases in development that expand the vulnerable asset base from 300 to 500 to 1000, and so on. Assuming that the severity of the catastrophic event remains constant within the range of 1 to 3, and presuming no change in mitigation or management, economic losses will continue to grow – that is, the scope of impact will continue to grow. In fact, this is precisely what has occurred in recent decades. Empirical evidence indicates that, apart from certain weather-related events associated with global warming and geopolitical issues related to terrorism, the frequency of catastrophes has not increased – yet the scope of social and financial impact has increased dramatically. This is attributable almost exclusively to growing vulnerabilities, which often expand without any meaningful change in mitigation or management behavior. Urbanization, social progress, and technological advancement have led to increased development over the past decades, and the pace of progress shows no sign of slowing.[9] However, if development continues without a

[9] Insurer Swiss Re's review of national disasters of the past 30 years suggests that insurance losses caused by disasters have risen dramatically as a result of higher property values and greater population densities in high-risk areas, rather than increased frequencies. Indeed, apart from spikes in terrorist activities and a growing incidence of certain types of storms owing to intensification of the hydrological cycle through global warming, there is no evidence to suggest the frequency of catastrophic events is rising. Loss growth

corresponding increase in risk management activities, a point must eventually be reached where the actual or potential losses become so large that mitigation/management must be employed – this state might be characterized as one of sustainable mitigation. Whether this will eventually occur is unknown. Ultimately, progress can be viewed as a form of risk amplification that can only be checked by proper risk mitigation/management.

Catastrophe risk must therefore be managed – failure to do so can have a tangible impact on the health and safety of society, and the supporting financial and economic structures that allow society to function. Since vulnerabilities have increased steadily during the latter part of the 20th century and into the millennium, the micro and macro implications of disasters are becoming more apparent. Consider, for example, that during the 1950s, total global losses attributable to natural disasters amounted to less than $50b. By the 1960s that figure had increased to over $70b, by the 1980s to more than $200b, and by the 1990s to more than $700b.[10] Losses in the early part of the millennium have continued to grow larger – including $90b in direct and indirect losses associated with the terrorist incidents of 9/11, and tens of billions of dollars attributable to hurricanes/typhoons in Florida and Japan and tsunamis in Asia. The trend towards increasing losses is on the rise, making active management more essential than ever.

Though the largest dollar amount of losses occur in industrialized nations (given their urbanization, development, and asset value/concentrations), the greatest financial impact is typically felt in developing nations, where the economic base is generally small and the ability to absorb losses is limited. Indeed, the resilience of an economy is a key factor in determining precisely how a nation will cope with an event. A moderate catastrophe has the potential of consuming up to 1% of a developing nation's gross domestic product, which has significant implications on long-term economic expansion; years of potential progress might be threatened by a single event.

1.4 CATASTROPHE AND THE RISK MANAGEMENT FRAMEWORK

The management of risk is a difficult endeavor, partly because risk is an abstract and dynamic issue. Risk cannot be seen or touched, though its ultimate impact can certainly be detected after physical or financial damage has been wrought. Catastrophic risk is even harder to manage, because its relative infrequency makes it difficult to measure. In addition, its low frequency/high severity characteristics can create a mindset that allows exposed parties to believe that the 'worst case scenario' will not occur. In fact, hazard perception is an important element of the risk management process; if individuals or firms do not believe that an event is likely to happen, risk management decisions will be very different than if they believe otherwise. Though media coverage has expanded awareness, much more education remains to be done.

Disasters cannot be eliminated. A tornado, cyclone, chemical spill, or terrorist bomb explosion will occur at some time. The event cannot be stopped, as it is a force of natural energy or human motivations; though there is some possibility of reducing certain types of disasters, rarely can they be eliminated completely. Accordingly, the only way for a risk-averse institution

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is largely, if not exclusively, a function of vulnerability growth. Separately, insurance broker Guy Carpenter estimates that growth in hazard areas over the past few decades has led to a doubling of real dollar damages every 14 years. Munich Re's estimates are even more striking, suggesting that economic damage from catastrophe has been doubling every 7 years since the 1960s.

[10] The Red Cross and Red Crescent estimate that during the 1990s alone, 2800 significant natural disasters created $700b of direct and indirect losses at the personal and institutional level; the human toll during this period was significant as well, with more than 500 000 lives claimed and over 1b indirectly affected.

to cope with this inevitability is to create a risk management program that is based on economically rational mitigation, loss financing, or reduction measures; in fact, it is incumbent upon those responsible for managing risk to consider the potential impact of an event, however remote, on financial resources, and construct a plan for dealing with the consequences.

The risk management discipline has become well established in the business world over the past few decades. Many companies and sovereigns are now accustomed to dealing with the high frequency/low severity financial and operating risks that impact their operations, and often do so through a multi-stage process centered on identification, quantification, management, and monitoring. This process allows exposures and financial resources to be managed in a diligent and efficient manner, and minimizes the likelihood of 'surprise losses.' The same type of risk management framework is applicable to catastrophic risks. Catastrophe risks can be identified, quantified, managed, and monitored, and adjustments to the program can be made as vulnerabilities increase or new exposures expand. We will develop a catastrophic risk management framework in the balance of the book by focusing on the nature of the perils and the specific locations where they can occur (identification), the deterministic and probabilistic models that can be used to evaluate catastrophe risks and their relative economic consequences (quantification), and the range of private and public sector techniques, mechanisms, and products that help exposed parties reduce potential losses (management and monitoring).[11] Though risk management tools and techniques exist, it will come as no surprise that they differ from those applied to high frequency/low severity risks, and depend heavily on assumptions and estimates. Throughout the text we shall highlight some of the challenges that exist when trying to evaluate and manage catastrophic risks through a formal framework.

While risk management is generally conducted by individual entities at a micro level, certain catastrophic events have the potential of generating such large direct and indirect losses that government authorities must participate in pre-loss crisis planning and post-loss emergency management and financing. This is especially critical when a regional or national disaster creates significant casualties and property destruction, or when the financial burden of reconstruction is so great that it overwhelms the capabilities of the private sector. It is therefore critical for government entities to create a risk management process that can be enacted quickly. Certain aspects of disaster recovery can only be conducted effectively at a regional or national level, as local efforts may prove inadequate, duplicative, or disorganized. Evidence suggests that governmental authorities in some hazard-prone countries have developed emergency risk management programs that can be implemented at short notice; they also have the necessary resources on hand to provide rapid access to post-loss financing. However, many others do not, and are susceptible to considerable difficulties should a disaster occur. This is particularly true of developing nations, which tend to lack the financial resources and risk management capabilities of the industrial world.

The state of the local economy dictates how quickly a crisis can be absorbed. Ultimately, a resilient economy that is capable of handling the financial shock of a catastrophe will fare better than one that is already in the midst of a contraction or structural dislocation, or which lacks the resources necessary to assist those that have been affected. Since major catastrophes may require a reallocation of financial resources from existing economic programs and planned

[11] Concerns can arise when risk decisions are made largely on the basis of subjective beliefs or reactions to recent occurrences, rather than objective measures and analysis; this increases the potential of taking overly conservative or liberal actions. Furthermore, in some societies the risk management process is regarded as irrelevant or a novelty, particularly when viewed in the context of larger social issues such as poverty, disease, or famine; a catastrophe is simply another element of the social condition – one that is more likely to be managed through external sovereign aid rather than coordinated micro-level risk management actions.

investments, economic goals can be jeopardized. Exports may also be disrupted, causing deterioration in the country's trade balance and a worsening of the balance of payments account.[12] Public borrowing may also be required if insufficient government funds exist, increasing the local/national interest burden (and possibly lowering the credit rating/increasing the general cost of funding at the sovereign level).

We shall discover in Part II of the book that the actual management of catastrophic risk is a multi-faceted approach that requires the expertise and resources of various private and public sector mechanisms. The natural reaction for those attempting to actively manage exposure to earthquake, hurricane, terrorism, or a sovereign financial event is to utilize insurance. In fact, insurance is one of the most efficient and resilient mechanisms available for dealing with low frequency/high severity risks. But insurance alone is not a sufficient solution. The growing scope of impact means that there is simply not enough insurance-based capital to provide coverage for all those seeking protection. Accordingly, alternative solutions must be factored into the process, including *ex ante* measures such as loss control/mitigation, and *ex post* loss financing via reinsurance, capital markets instruments, and public funding. Only when combined is an economy likely to be able to withstand the onset of one or more large disasters.

1.5 OVERVIEW OF THE BOOK

With this brief overview of catastrophe risk in hand, we are now prepared to examine the topic in greater detail. In the balance of Part I we continue with our focus on identification and quantification:

- In Chapter 2 we commence our discussion of specific catastrophic perils, focusing on both natural and man-made disasters and how they occur. We do not intend to provide a technical, scientific, or socio-political discussion on why disasters happen, or an exhaustive catalog of all the events that have occurred in the past few decades. Rather, we illustrate some of the basic concepts of disasters and support the topic by providing select examples.
- In Chapter 3 we extend the discussion on identification by considering vulnerable areas by geographic region. Since disasters may or may not be constrained by natural or geopolitical boundaries, a regional perspective provides an understanding of areas that are at risk, which is an important consideration when attempting to determine the scope of potential losses.
- In Chapter 4 we consider the second essential element of the risk management process, quantification. Once risk exposures have been identified it is necessary to consider the financial impact they can have on operations, and our discussion on catastrophe risk modeling provides direction in this area.

In Part II we will utilize the analysis tools developed in Part I to understand how catastrophic risks can be managed:

- In Chapter 5 we consider catastrophic exposures in light of the holistic risk management framework, examining the concepts of enterprise value maximization, solvency, and liquidity in relation to loss control, loss financing, and risk reduction. This approach helps us understand the relative advantages, disadvantages, opportunities, and limitations of the private and public risk management efforts that form our discussion in the balance of Part II.

[12] As an example, one research study has found that in the 5-year period following the devastating Mexico City earthquake of 1985, the country's balance of payments deficit increased by $8.6b.

- In Chapter 6 we analyze the insurance and reinsurance mechanisms that are available to ceding companies and ceding insurers attempting to manage their catastrophic exposures. We examine issues related to mechanics, structure, pricing, and market cycles, as well as challenges and limitations.
- In Chapter 7 we continue the discussion of management solutions by examining alternatives from the capital markets. Gradual convergence of the insurance and financial sectors has led to the creation of new mechanisms for transferring and hedging risk exposures, and we analyze several of the most significant, including catastrophe bonds and contingent capital. In order to understand how such solutions interact with, or substitute for, insurance/reinsurance, we also consider structure, pricing, and capital supply characteristics, as well as challenges and shortcomings.
- In Chapter 8 we extend our discussion of capital markets risk management by analyzing the role of derivatives, with a specific review of the features and limitations of exchange-traded and over-the-counter catastrophe contracts.
- In Chapter 9 we shift our focus from the private sector to the public sector by examining programs that are funded and directed by federal, regional, or local governments. As noted, some disasters are so large (and/or are located in countries lacking private sector transfer mechanisms) that the role of sovereign authorities in providing financial and technical assistance is imperative.
- In Chapter 10 we conclude our work by examining challenges facing the catastrophic risk management sector in the dynamic social and economic world of the millennium.