

Management report

Monte Carlo-based risk assessment

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*A Gioia,
Caterina, Leonardo e Ludovico*



*Hurricane
Claudette at
1.00 pm of
17 July 2003.*

Hurricane Claudette forces shutdown of 264 platforms, 41 drilling facilities and nearly a quarter of gulf production.

By the time Claudette struck Texas coast on July 15, operators had evacuated 264 offshore platforms and curtailed production amounting to 332,942 barrels per day of oil and 2.536 billion cubic feet per day of natural gas. That hit represented about 21% of normal daily production of 1.6 million barrels and 18% of daily natural gas production of 14 billion cubic feet. Claudette and her 80-mph winds appeared to have caused far more damage onshore than offshore. Last year offshore producers were hit hard by back-to-back storms: tropical storm Isidore followed by hurricane Lilli between September 23 and October 18. Mineral Management Services (MMS) estimated that more than 14.4 million barrels and 88.9 billion cubic feet of natural gas were unavailable for US consumption because of the shutdown of oil and gas operations in the gulf. (*Petroleum News*, 8, 29, July 2003)

Hurricane Claudette moves crude oil prices higher

Crude oil and retail gas prices have inched higher over concerns about Hurricane Claudette, according to the AAA Texas Monthly Fuel Gauge Report Statewide, the price for a gallon of regular self-serve gasoline is averaging \$1.42, up two cents since June 17. Last year at this time, gas prices were averaging \$1.29 in Texas. Nationally, the average price of gasoline is \$1.52, compared to last month's average of \$1.50 and last year's average of \$1.39. In Houston, motorists are paying \$1.42 per gallon in July, compared to \$1.31 in July 2002. Last month, Houston motorists shelled out an average of \$1.40 per gallon. "The small increase is partly due to fears about Hurricane Claudette which has temporarily disrupted some refining and petroleum shipping in the Gulf of Mexico," said Rose Rougeau, spokeswoman for AAA Texas. (*Houston Business Journal*, 14 July 2003)

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Executive summary

This report focuses on the use of Monte Carlo-based methods to solve risk assessment problems. The discussion is centred on a real business case: the National Gas Corporation (NGC) of Trinidad and Tobago is negotiating its insurance policy for the forthcoming 10 years, and has asked Sigma-Risk, an insurance company, advice on the level of deductibles that it should agree upon. NGC has asked Sigma-Risk to consider the fact that climate change may increase the levels of weather-related losses in the forthcoming years and has asked whether it should implement a set of control measures aimed to reduce them. The two general conclusions of this report are:

- A probabilistic approach to risk assessment is superior to a deterministic one, since it provides the entire probability distribution function of a company's risk profile. Monte Carlo-based methods can generate such a distribution function.
- There are four key stages in a probabilistic risk assessment process: the definition of the problem and of the decisions that need to be taken, the definition of the measures associated with the decision process, the definition of the input data, and the construction of the simulation model.

Considering the specific NGC's business case, under the assumption that climate change may affect weather-related risks NGC's best choice is to renew its insurance policy with "option C"¹ deductibles, and to start implementing a set of control measures aiming to reduce the potential impact of weather-related losses from year 1. Monte Carlo-based simulations have indicated that these decisions would keep risks' levels to values acceptable by NGC.

1 Deterministic and probabilistic risk assessment approaches

In risk analysis, the estimation of the probability distribution of potential losses is often limited to the computation of the most probable potential loss related to the risk under consideration. This ‘deterministic’ limitation is based on two key assumptions: that there are no uncertainties in the model or the input data, and that the most probable scenario is what matters most.

But reality is so complex that risk assessment models can only describe it approximately, and input data are usually a finite sample of the whole population of events that one should consider. Furthermore, a deterministic approach that is based on the computation of only the most probable outcome cannot provide probabilities of occurrence of low frequency, high severity, catastrophic events (e.g. loss of operation facilities, extreme variations in exchange rates), i.e. of events that differ substantially from the mean. Unfortunately, these extreme events are the ones that may cause severe financial losses, and the knowledge of their probability of occurrence is fundamental. It is thus of paramount importance that the deterministic approach is abandoned, and a probability approach is followed, whereby the whole distribution function of future risks is estimated. Monte Carlo methods can be used to estimate this probability distribution function.

This report discusses the use of Monte Carlo-based methods to assess deductible levels of the next 10-year insurance contract that an oil company should negotiate. Furthermore, Monte Carlo-based methods are used to assess the impact of climate

¹ Option C has the highest levels of deductibles, higher than the ones specified in the current policy. See

change on weather-related potential losses, and whether the company should implement a set of control measures designed to mitigate the potential risk increase that climate change can induce (i.e. a real option problem).

The report is organized as follows. In sections 2 and 3, the problem of the estimation of the total cost of insurance cover and Monte Carlo-based risk assessment methods are briefly reviewed. Then, in section 4 the Monte Carlo-based risk-assessment model used to solve the real business case is introduced, and in sections 5 and 6 the solution of the business case is discussed. Finally, in section 7 some general conclusions on the probabilistic risk-assessment process are drawn.

The two general conclusions of this report are:

- A probabilistic approach to risk assessment is superior to a deterministic one, since it allows company's executives to assess the probability of any event deemed to be important for the company's future operations. Monte Carlo-based methods can be used to generate such a probability distribution function.
- There are four key stages in a probabilistic risk assessment process: the definition of the problem and of the decisions that need to be taken, the definition of the measures associated with the decision process, the definition of the input data, and the construction of the simulation model. All stages must be carefully considered.

the case description in section 4, with deductibles listed in Table 5.

Considering the specific business case, the key conclusion is:

- Under the assumption that climate change does increase the potential losses due to weather-related risks², NGC is advised to renew its policy with “option C” levels of deductibles, and to implement a set of control measures aimed to reduce the potential damage associated with weather-related events. Monte Carlo-based simulations have indicated that only by taking these two decisions the probability of severe losses remains below NGC’s acceptable thresholds. Since there is evidence (Appendix D) that climate change is indeed having an impact on the intensity of weather events and thus on the severity of weather-related losses, NGC is advised to consider these two decisions as the solution of its problem.

2 Risk and insurance for offshore oil and gas operations

The oil and gas industry is risk taking by nature: any company operating in this sector should carefully consider its insurance programme, and accurately define the size of the policy deductibles. The only few exceptions are companies that have reached such a size that they can decide to assume all their own risk, and operate under a “no insurance”³ philosophy.

² If one assumes that climate change does not increase the potential losses due to weather-related risks, than NGC is advised to renew its policy with the current levels of deductibles, since with this option the probability of severe losses is below NGC’s acceptable thresholds, and the associated total insurance costs is lowest.

³ A “no-insurance” policy is sometimes named a “self-insurance” policy.



Exhibit 1. 20 March 2001. The world's largest offshore oil rig sank, five days after powerful blasts (blow-out) ripped through the platform killing 10 people. Petrobras stated that all 1.5 million litres of crude and diesel stored on and under the platform were likely to spill into the ocean.

2.1 Market forces, behaviour and the price of insurance coverage

The price of any insurance depends on a variety of issues, which can be classified under three main categories [17]:

- Technical price
- Commercial price
- Behavioural price

The technical price (Exhibit 2) comprises three main elements: the risk-based price, the general costs, the sales costs and the expected margins. The risk-based price depends on the probability that events with a certain loss may occur and on the severity of such a loss, and can be computed either using a statistical analysis of past events, by integrating models that can simulate the expected future potential losses, or by a combination of both methods.

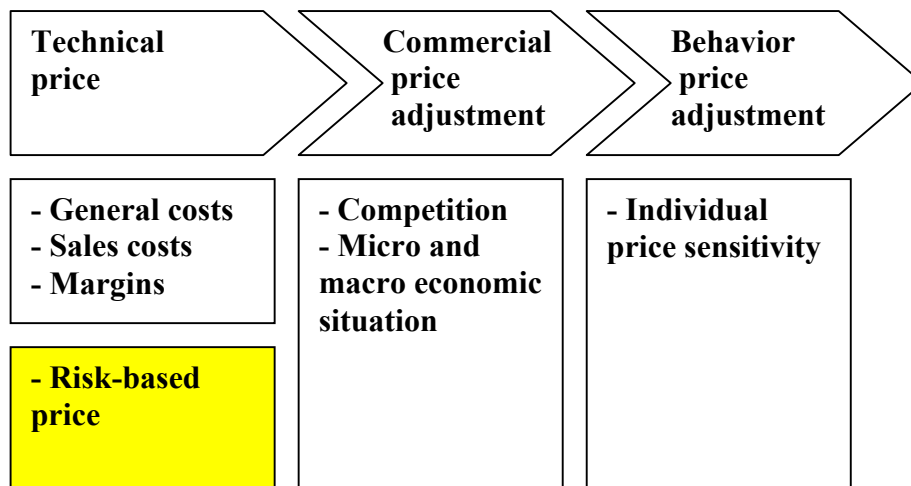


Exhibit 2. Insurance price components [17].

The commercial component of an insurance price represents the adjustment to market conditions, e.g. due to competition: prices for insurance coverage move up and down as capacity⁴ moves in and out in the industry, with a typical cycle lasting between 5 and 7 years [14]. For smaller risks, there is usually an over-supply of insurance capacity, resulting in competitive rates, but for risks that involve large values, the availability of enough capacity has a stronger impact on the price of the insurance coverage.

⁴ Capacity; amount of shareholder capital available to secure new business.



Exhibit 3. Three views of Hurricane Andrew as the hurricane moves East to West towards Louisiana on the 23rd, 24th and 25th of August 1992 (GOES-7 images, from rsd.gsfc.nasa.gov/rsd)

A downward cycle is generally triggered by a period of heavy losses. For example [14], between 1987 and 1993 the insurance industry lost billions of dollars due to a series of unfortunate events: the Piper Alpha platform in the North Sea, the Exxon Valdes super-tanker polluting the coasts of Alaska, hurricanes Hugo and Andrew (Exhibit 3), the San Francisco earthquake. To raise enough cash to pay for heavy losses, the insurance companies have to drop premiums very fast. Insurance prices reach a minimum and start to rise again when they become unsustainable. The downward cycle of 1987-1993 reached the lowest prices in 1991-1993. Rates then continue to raise attracting new capacity in the industry. At some point insurers start writing “bad” risks (under priced) to fill the over capacity in the industry. This increases the probability of heavy losses, thus triggering the cycle again.

The behavioural aspect of the insurance price identifies the fact that two customers with the same risk profile may be prepared to pay different prices for the same insurance

policy, e.g. because one of them has more information and is able to negotiate a better price.

In this report, attention focuses on the problem of the estimation of the risk-based component of the technical price.

2.2 Risk control, risk retention and risk transfer

In order to calculate the risk-based component of the technical price, first the sources of risk must be identified. Then, one should consider whether to adopt a set of measures that could control⁵ the risk (i.e. reduce the associated loss), and decide which risks should be retained⁶ (i.e. the levels of deductibles) and which should be transferred, typically via an insurance contract. As it will be clear in the case discussion, these two decisions on control measures and risk transfer should be taken in parallel and not sequentially, since they can affect in a non-linear way the total cost of insurance. The total cost of risk, also called the total cost of insurance, is defined as the sum of the costs of control measures, of the insurance contract and of the self-insured deductibles.

It is important that the risk-assessment process is revised regularly, especially during periods of uncertainties about the company's financial conditions, the market conditions or the sources of risk. For example, when insurance premiums are high, it may be optimal for a company to retain (i.e. self-insure) certain aspects of risk, but a change in the market conditions may require a different decision.

⁵ Risk control can be achieved via training, maintenance and catastrophe planning.

⁶ Risk retention can be obtained by negotiating a larger deductible in exchange for a lower premium

2.3 Categories of risk

Exhibit 4 shows the main causes of worldwide offshore operating losses, based on the top 30 operating losses between 1980 and 1990 [1]: the two main categories, fire (which includes also lightning and explosion) and blow-out, explain 84% of the total losses.

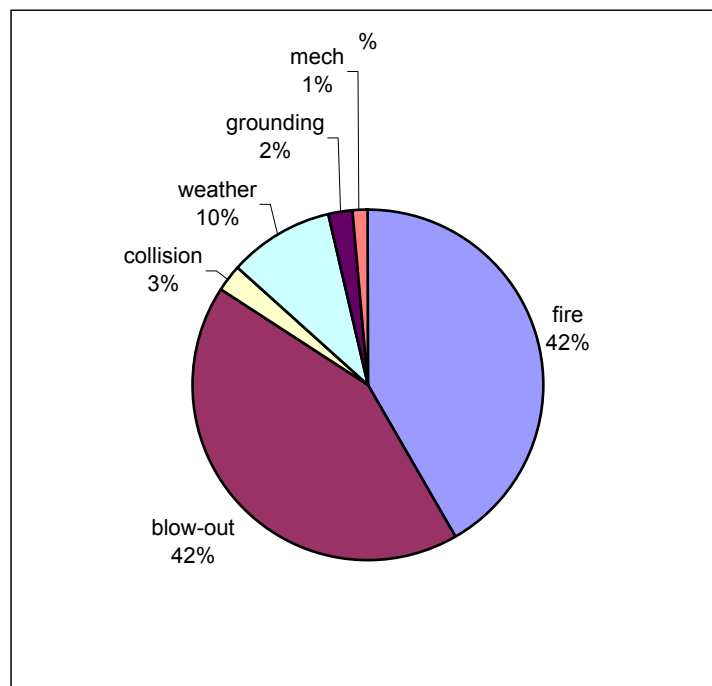


Exhibit 4. Causes of the top 30 offshore operating losses between 1980 and 1990, expressed in terms of the relative contribution to the total loss [1].

For NGC, the four most prevalent risks are linked to damages to property (i.e. a platform or a mobile rig, pipelines), damages to the environment (i.e. pollution), financial losses due to operation disruption and loss of human lives or bodily injury.

3 Estimation of the risk-based price using Monte Carlo methods

The two fundamental differences between a deterministic and a probabilistic approach to risk assessment are that the latter one can simulate the effect of uncertainty in the model formulation and in the input distributions, and that it generates the whole probability distribution function of risk. The information content of this distribution is superior to a deterministic single estimate, and allows estimating the probability that total losses could exceed thresholds T_i that may cause financial disruption. In the following sub-sections, some key concepts of Monte Carlo methods are briefly reviewed: as an example, a simplified version of the NGC’s case will be discussed in the following section.

3.1 Computation of the risk-based price: a simplified example

Assume that NGC’s executives want to estimate the expected risk-based price for next year. Suppose that there are only 3 types of risks, classified under categories “platforms”, “offshore pipelines” and “onshore pipelines”, and that using past data they have computed the average value x_j and the average frequency (i.e. number of events per annum) k_j for each event (Table 1).

	<i>Platforms</i>	<i>Offshore Pipelines</i>	<i>Onshore Pipelines</i>
Number of events per decade k_j	9.09%	18.18%	9.09%
Average risk-based price x_j (USD)	243,000	2,504,000	210,000
Expected risk-based price (calculated figure, USD)	496,455		

Table 1. Average frequency and average value of risks in categories platforms, offshore and onshore pipelines (data extracted from the NGC case, section 4).

Using these data, the expected risk-based price $\langle x \rangle$ can be computed as a weighted average

$$(1) \quad \langle x \rangle = \sum_{j=1}^3 k_j \cdot x_j$$

This estimate is based on two very strong assumptions: the fact that frequency is constant and equal to the average value, and the fact that losses are constant and equal to the average value. An accurate analysis of the dataset (see Table 4 in section 4) of past losses does indeed suggest that the risk-based frequency and price are not constant but vary: for example, losses in the category “Offshore pipelines” have occurred twice in the past 11 years, with associated value of 1.258 and 3.650 million USD.

The first step to relax the two assumptions on the frequency and value is to allow the frequency to be defined by the whole frequency distribution function $f_j(k)$, computed such that it fits⁷ the frequency dataset (Table 2). It is then possible to generate an ensemble of N possible future scenarii by sampling N frequency values from the frequency distribution function, and finally to estimate the distribution of potential losses by multiplying each frequency by the average value.

	<i>Platforms</i>	<i>Offshore Pipelines</i>	<i>Onshore Pipelines</i>
Frequency distribution	$f_A(k)$	$f_B(k)$	$f_C(k)$
Average risk-based value x_j (USD)	243,000	2,504,000	210,000

Table 2. Frequency distribution and average value of risks in categories platforms, offshore and onshore pipelines (data extracted from the NGC case, section 4).

For each risk category j , it is crucial to assume a “realistic” functional form for the frequency distribution function $f_j(x)$, where realistic means that the frequency distribution function agrees with the data-set of past events. In this report, it has been assumed that all frequency distributions are Poisson functions⁸

$$(2) \quad P(\lambda, x) = \frac{e^{-\lambda} \lambda^x}{x!}$$

where the parameter λ is the average number of events in a given time period. In the NGC’s case, λ has been computed from a dataset which includes 11-years of past events.

Once the risk-based frequencies have been estimated, the expected value of the risk-based price can be computed as

$$(3) \quad \langle x \rangle = \int_0^{+\infty} \sum_{j=1}^3 f_j(k) \cdot x_j dk$$

The key difference between Eq. (1) and Eq. (3) is that in this latter case one has to compute an integral, a computation that may need to be performed numerically.

To further increase the accuracy of the estimated risk-based price, it can be assumed that also the risk-based price associated with each category is not constant and equal to the average value, and replace it with a distribution function (Table 3). If this approach is followed, then each member of the ensemble of future scenarii is characterized by a

⁷ In an optimum way, e.g. using least-squared minimization methods.

⁸ Papoulis, A, 1994. Poisson process and shot noise. Ch 16 in *Probability, Random variables and stochastic processes*, 2nd ed. New York, McGraw-Hill, pp 574-576.

frequency sampled from the frequency distribution and a risk-value sampled from the value distributions.

	<i>Platforms</i>	<i>Offshore Pipelines</i>	<i>Onshore Pipelines</i>
Frequency distribution	$f_A(k)$	$f_B(k)$	$f_C(k)$
Risk-based distribution (USD)	$v_A(k)$	$v_B(k)$	$v_C(k)$

Table 3. Frequency and value distribution functions for categories platforms, offshore and onshore pipelines.

This is the approach followed in this report, where it has been assumed that the value distributions are Log-normal functions,

$$(4) \quad v(k) = \frac{e^{-\frac{1}{2} \frac{(\ln k - \ln k_0)^2}{\sigma^2}}}{\sigma \cdot \sqrt{2\pi}}$$

with the distributions' mean and standard deviations assumed to be equal to the average loss during the last 10 years.

Once both the frequency and the value distribution functions have been estimated, the expected value of risk-based price can be computed as

$$(5) \quad \langle x \rangle = \int_0^{+\infty} \left(\sum_{j=1}^3 f_j(k) \cdot v_j(k) \right) \cdot dk$$

The computation of this integral is usually complex and can only be performed numerically using Monte Carlo methods.

3.2 Monte Carlo methods applied to the estimation of the risk-based price

The easiest form of a Monte Carlo integration of the integral in Eq. (4), can be summarised as follows [7, 15]:

- For each j , define the input distributions $f_j(k)$ and $v_j(k)$
- From these distributions draw values F_j and V_j : for each couple of values compute the products $F_j \cdot V_j$, and generate the probability density function of the products $f_j(k) \cdot v_j(k)$

Once the probability density function is known, it can be used to compute the expected value and the standard deviation of the distribution, which can be used as an indication of the spread of the potential outcomes, or to compute any other compound function⁹ of the output distribution function. The two main strengths of the Monte Carlo technique are its simplicity and the completeness of its output. Simplicity is linked to the fact that the numerical computation is made of N numerical simulations of the same model with different parameters' settings and input values. Completeness is linked to the fact that it provides the entire distribution function of risk-based price and not only its first order-moment, the average price.

⁹ The probability of occurrence of a certain output is, for example, given by an integral of the output distribution function.

4 Risk assessment at Sigma-Risk

The business case analyzed in this report is set in 1997, and involves two companies, the National Gas Company (NGC) of Trinidad and Tobago (T&T) and Sigma Risk Management Inc. NGC is due to renew its “All Risks” insurance policy, and has asked Sigma Risk for advice.

4.1 *National Gas Corporation of Trinidad & Tobago Limited*

The National Gas Corporation (NGC) of Trinidad and Tobago was created in 1975 to purchase, transport and sell natural gas in Trinidad and Tobago. Since its establishment, NGC has played a vital and leading role in the development of Trinidad and Tobago’s natural gas-based energy sector. Over the years, NGC’s business has grown to include offshore gas compression and, since 1992, gas-based project development and investment promotion. NGC has the responsibility of ensuring the optimum development of the natural gas industry for the benefits of all citizens of Trinidad and Tobago.

In 1996, NGC had fixed assets worth USD 113 million (Appendix A), which included pipeline infrastructure, port and marine facilities at Port Point Lisas, industrial sites and two gas compression platforms located off the south-east coast of Trinidad. NGC’s growth policy for the forthcoming 5 years was expected to increase the amount of fixed assets to over USD 300 million. Table B.1 in Appendix B lists key financial indicators for 1996, 1997 and 1998.

NGC’s portfolio of assets and activities makes it exposed to a variety of risks, including fire, weather storms, blowout and mechanical failure.

4.2 *Sigma Risk Management Inc*

Sigma Risk Management Inc is a specialized risk and insurance management-consulting firm, offering services to corporate clients. The company was established in 1992 and has offices in Calgary and San Francisco with associate offices in the U.K., France and Argentina. Sigma-Risk's business purpose is to help its clients manage their operational risks more knowledgeably and cost-effectively, by providing them with technical advice and assistance with risk analysis, risk management, self-insurance, and insurance.

Since 1985, Sigma's consultants have operated in the Caribbean and are arguably the most experienced independent risk management consultants in the region. Caribbean clients have included petroleum and utility companies, manufacturers and marine operators. Sigma has recently developed a Monte Carlo-based, probabilistic risk assessment model for use in risk financing, self-insurance, and insurance decisions. This model should help Sigma to increase the accuracy, and therefore the value, of its estimates.

4.3 *The business case¹⁰: insurance deductibles and total cost of insurance*

April 1997. NGC is due to renew its "All Risk" policy for the next 10 years, and has asked Sigma Risk for advice on property insurance deductibles. NGC owns two offshore platforms, various pipelines and surface facilities and some harbour facilities.

¹⁰ This business case has been written by the author inspired by a simplified real case, under the supervision of Prof Z. Degraeve. Tables 4 and 5 summarize the key data of the original business case: the complications arising from the impact of climate change and the (real) options to adopt/install control measures to reduce damages have been added to the original case by the author.

The NGC's Vice President of Administration is considering increasing NGC's insurance deductibles for these assets: this would lower the cost of the insurance policy, but would expose NGC to higher risk in the form of increased self-insured losses (i.e. deductible payments).

In 1996 NGC reported profits of USD 85 million, but it was not expecting to record an increase in profits for the forthcoming years. NGC's executives decided to adopt two criteria to decide the acceptable level of deductibles:

- The maximum potential total cost of insurance had to be lower than USD 6 million
- The probability that the total cost of insurance exceeded USD 2 million had to be lower than 15% and the probability that the total cost of insurance exceeded USD 4 million had to be lower than 5%

<i>Year</i>	<i>Loss</i>	<i>Amounts inflated to 1996 USD</i>
1985	Damage to offshore pipeline	1,258,000
1988	Fire damage to regulator station machinery	658,000
1990	Compressor breakdown (platform)	243,000
1995	Damage to Offshore Pipeline	3,750,000
1995	Damage to onshore Pipeline	210,000

Table 4. NGC's property losses (1985-1995 included), expressed in terms of 1996-USD.

Table 4 lists NGC’s non-catastrophic losses over the past 11 years, to which allowances for catastrophic events linked to hurricanes and earthquakes with the following characteristics should be added:

- Class-3 hurricanes (such as Claudette, see page 3), which could result in an average loss of USD 1 million, can occur once every 25 years. Deductibles for hurricanes are 5% of total loss.
- Earthquakes, which could result in an average loss of USD 5 million, can occur once every 100 years. Deductibles for earthquakes are 5% of total loss.

	Average frequency of event (per decade)	Average damage per event (1996-USD)	Deductibles of insurance alternatives			
			current	option A	option B	option C
Platforms	9.09%	243,000	250,000	1,000,000	2,000,000	5,000,000
Offshore Pipelines	18.18%	2,504,000	250,000	1,000,000	2,000,000	5,000,000
Onshore Pipelines	9.09%	210,000	25,000	100,000	200,000	200,000
Hull and Machinery et al	9.09%	658,000	25,000	100,000	200,000	200,000
CAT - Hurricanes	4.00%	1,000,000	50,000	50,000	50,000	50,000
CAT - Earthquake	1.00%	5,000,000	250,000	250,000	250,000	250,000
Cost of Insurance policy			1,480,000	1,010,000	785,000	515,000

Table 5. Average decadal frequency of event, average damage per event (expressed in 1996-USD), and deductibles for four different insurance alternatives. Deductibles for catastrophic events hurricanes and earthquakes have been set to 5% of the average damage.

Table 5 lists renewal quotations for NGC’s property insurance against non-catastrophic (categories platforms, offshore and onshore pipelines and hull and machineries) and

catastrophic (hurricane and earthquakes) events. NGC has been offered four options: the current level of deductibles, and options A, B and C with increasing deductibles but decreasing the cost of the insurance policy.

NGC has been worrying about published claims [3, 4, 5, 6] that climate change may induce an increase in both the frequency and the severity of weather events, such as wind-storms and hurricanes, and has asked Sigma-Risk to simulate also a “hot climate scenario” (NGC has estimated that climate change could affect the risks associated with the weather-sensitive categories “platforms”, “offshore pipelines” and “CAT - hurricanes”).

Finally, NGC has been considering the option to implement some “control” measures (wave-breaking barriers, re-enforcements, use of different construction materials, staff training) that could compensate for the increased weather-related damage that climate change may induce. NGC has estimated that the implementation of these measures would take 3 years, at an annual cost of \$200,000 per year (nominal, and constant during the forthcoming years). After completion, weather-related average damages would decrease by about 15% per year up to a minimum level, estimated to be equivalent to 50% the current level (NGC has estimated that further investments would be required to achieve more substantial damage reductions). Any implementation delay of these measures would reduce the present-value of the total cost, but would clearly delay the positive effect of the measures.

The four key questions that NGC wants to be addressed are:

- Q1. What are the expected and the maximum total risk-based prices for different levels of deductibles, and what are the self-insured and the insured part of each for the different levels of deductibles?
- Q2. What is the probability that the total risk-based price exceeds USD 2 and 4 millions?
- Q3. Would the answer to the previous two questions change in a “hot climate scenario”? Which insurance option should NGC subscribe in this case?
- Q4. Shall NGC implement the planned control measures to reduce the average loss due to weather-related events? Would it be best to start the implementation works in year 1, or delay it until year 4?

5 The NGC’s Monte Carlo-based risk-assessment model

Table 4 provides the average frequency and the average magnitude of the losses for the six categories of risk to which NGC is exposed. Sigma-Risk model is based on the assumption that each frequency distribution is a Poisson¹¹ function

$$(5) \quad f(k) = \frac{e^{-\lambda T} \cdot \lambda^k}{k!}$$

where λ is the average frequency, and each value distribution is a lognormal¹² function

¹¹ Consider an event that has a probability of occurrence λ in a time interval dt : the Poisson distribution gives the probability that this event can occur k -times over a time span $[0, T]$.

$$(6) \quad v(k) = \frac{e^{-\frac{1}{2} \frac{(\ln k - \ln k_0)^2}{\sigma^2}}}{\sigma \cdot \sqrt{2\pi}}$$

where $\ln(k_0)$ and σ denotes the mean and standard deviation of the logarithm of the values.

Given these input distributions, the Monte Carlo-based model (Appendix C) generates the output distribution function of total losses (“no-insurance” policy), and the distribution of self-insured losses for each of the four options of deductibles. For each option, the total cost of insurance is given by the sum of the self-insured losses and the cost of the insurance policy.

5.1 Input distributions

The non-catastrophic events reported in Table 4 have been classified in four different types of risks: “platforms”, “offshore pipelines”, “onshore pipelines” and “hull and machineries”. Using the data reported in Table 4, and the additional information provided in the case regarding the two catastrophic events, the average frequency and the average risk-based price for each of the six categories have been computed: values are reported in the first two columns of Table 5.

¹² A variable follows a lognormal distribution if its natural logarithm is normally distributed. Returns are usually assumed to be log-normally distributed. The lognormal distribution is always positive.

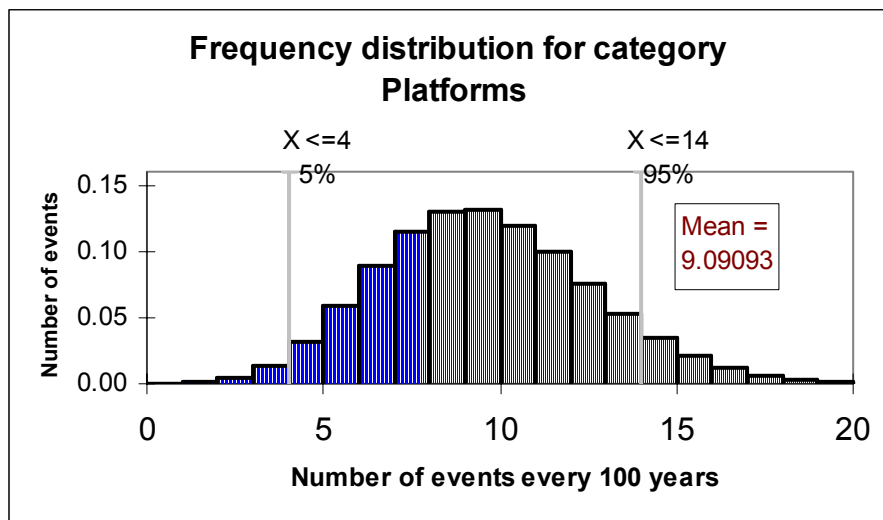


Exhibit 5. Input frequency distribution functions for risk-based events in category 'Platforms'. Abscissa is number of events per century.

Exhibit 5 shows the input frequency distributions for the risk-based category “platform”, expressed as a function of the number of events per hundred years. For example, this graph shows that there is a 6% probability that there will be 6 events in the next 100 years, that the average decadal frequency is 9.09% (as imposed).

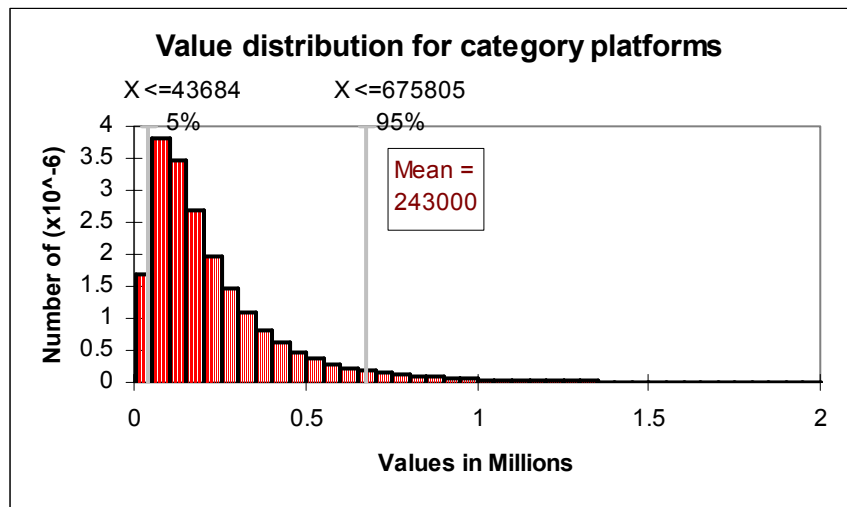


Exhibit 6. Input value distribution functions for risk-based events in category 'Platforms'. Abscissa is million USD.

Exhibit 6 shows the risk-based value distribution for the risk-based category “platform”. Note that, although the bulk of the distribution is centred on the mean value of \$243,000, a long tail characterizes the distribution, with potential damages reaching \$1.3 million per event.

Given any distribution function $f(x)$, an alternative way to show it is in terms of its cumulative function

$$(7) \quad F(X) = \int_{-\infty}^X f(y) \cdot dy$$

which gives the probability that the variable x , which is distributed as described by the function $f(x)$, has a value smaller or equal to X

$$(8) \quad P(x \leq X) = F(X) = \int_{-\infty}^x f(y) \cdot dy$$

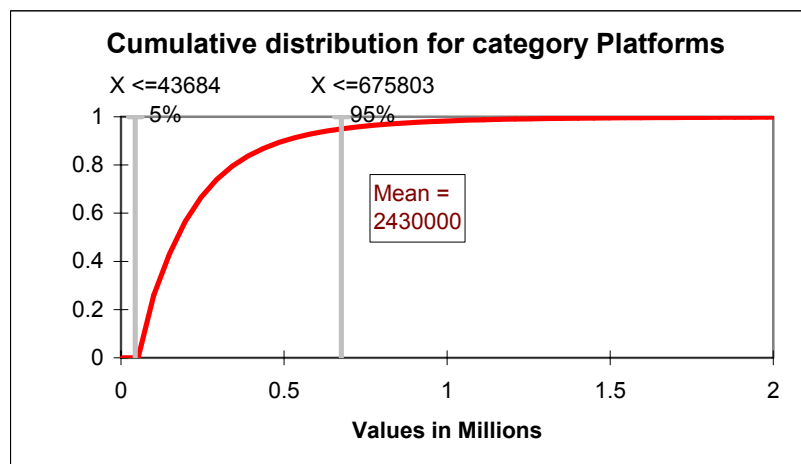
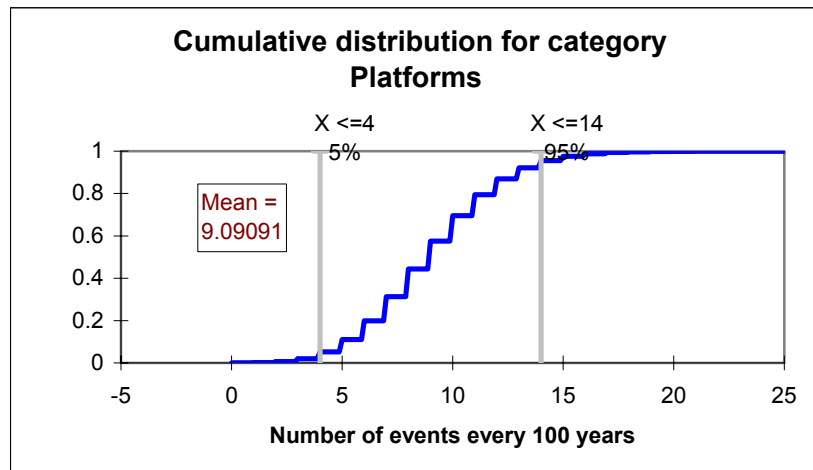


Exhibit 7. Input frequency (top) and value (bottom) cumulative functions for risk-based events in category 'Platforms'. Abscissa for top panel is number of events per century, and for bottom panel is million USD.

Cumulative distribution functions can be interpreted more easily than distribution functions. For the case of risk-based category 'platforms', for example, the top panel of Exhibit 7 shows that there is about a 40% probability that more than 10 events could

occur in 100 years, and the bottom panel shows that there is a ~2% probability that each single event may induce a loss of more than USD 1 million.

5.2 Output distributions

Exhibit 8 shows the output distributions for the total cost of insurance, defined as the sum of the cost of insurance (from Table 5) and the cost linked due to the self-insured losses (no control measures are considered in this scenario). The “no-insurance” case represents the distribution of total losses that NGC will be facing in the next decade. These graphs show that the output distributions are non-standard functions, with rather long tails, and that the higher the level of deductibles, the longer the tail of the distribution towards high values (see, e.g., the cases of option A versus C).

These distributions can be used to compute some more specific estimates that condense the amount of information that they contain, such as the expected value, the maximum loss, and the probability that total losses would exceed certain values. Results (Table 6) indicate that if NGC decides to undertake insurance with option B deductibles there is an 0% probability that in the next decade it will incur a total cost higher than USD 4 million, while signing option C would increase this probability to 4.2%.

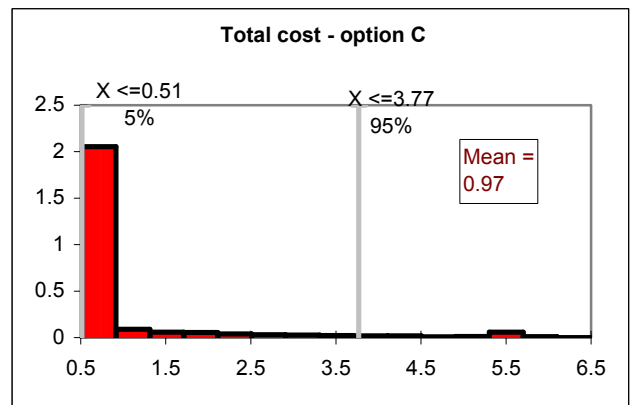
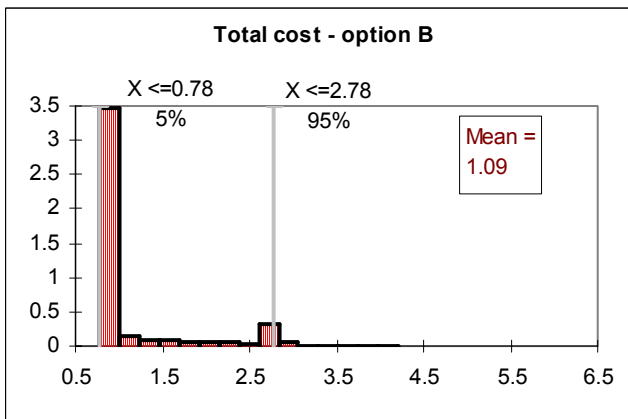
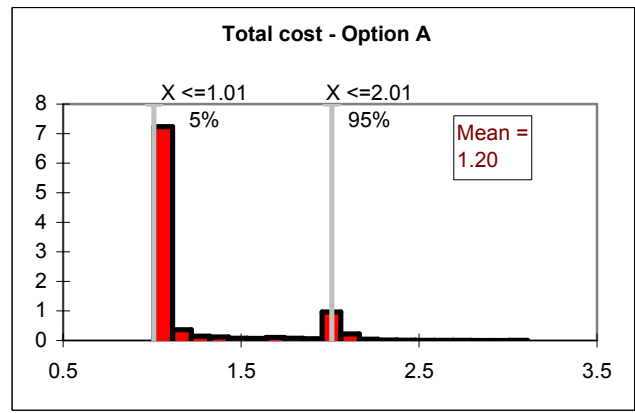
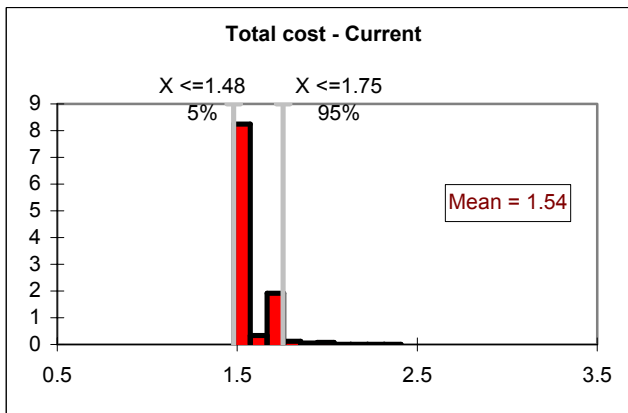
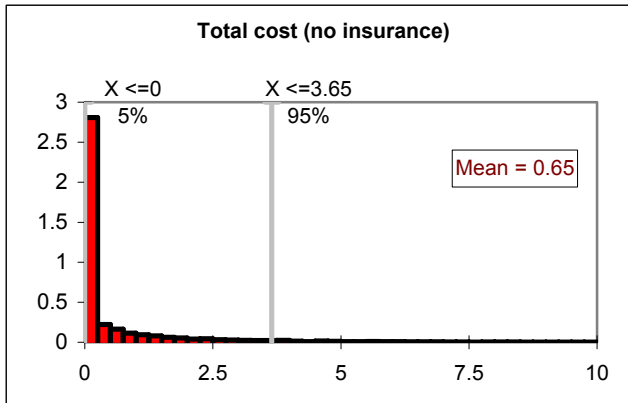


Exhibit 8. Total insurance cost, defined as the sum of the cost of the insurance policy plus deductibles, for the case of no insurance (top left), current schedule (middle left), and options A (middle right), B (bottom left) and C (bottom right). Please note that the abscissa scale (in million USD) changes in the panels.

	No ins	Current	Option A	Option B	Option C
Pr(TC > 1 ml)	16.8%	100.0%	100.0%	21.3%	16.8%
Pr(TC > 2 ml)	10.0%	0.2%	13.0%	11.7%	10.4%
Pr(TC > 3 ml)	6.3%	0.0%	0.0%	0.5%	6.6%
Pr(TC > 4 ml)	4.1%	0.0%	0.0%	0.0%	4.2%
Pr(TC > 5 ml)	2.8%	0.0%	0.0%	0.0%	2.8%

Table 6. Probabilities that the total cost of insurance in the next decade will exceed USD 1, 2, 3, 4 or 5 million for all insurance options. Policies “no insurance” and “option C” fail to satisfy NGC’s constrain that $P(TC > 4ml)$ is lower than 5%.

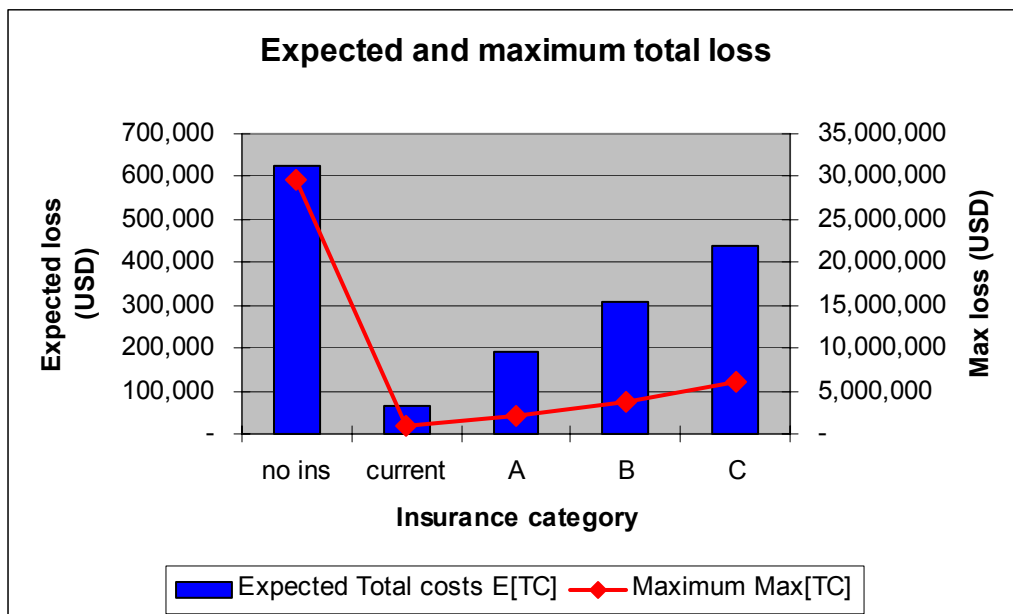


Exhibit 9. Expected (blue bars, right axis) and maximum (red line, left axis) total cost of insurance for all insurance options. Policies “no insurance” and “option C” fail to satisfy NGC’s constrain that the potential maximum loss is lower than USD 6 million.

Exhibit 9 shows the expected and the maximum total cost for the different insurance options: the maximum total cost is defined as the maximum total cost detected in the simulation; this gives an upper bound to the total cost of insurance.

It is interesting to note that the “no-insurance” policy option has the lowest probability that the total cost will be higher than USD 1 million (Table 6), but it is associated with the highest maximum potential loss value. (It is worth reminding that NGC has put an upper limit of USD 6 million on the maximum loss that it can face: due to this constraint the “no insurance” policy cannot be considered as a viable option¹³.)

These results address the first two questions that NGC posed to Sigma Risk.

- Q1. Exhibit 9 summarizes the expected and maximum total cost of insurance for the different levels of deductibles. Results indicate that only insurance options “current”, “A” and “B” have maximum values lower than USD 6 million. Results also indicate that switching policy from “current” to option A, B or C would increase the potential maximum total cost of insurance by a factor of 3, 4.8 and 6.9, respectively.
- Q2. For these three options (“current”, “A” and “B”), Table 6 lists the probabilities that the total cost of the insurance will be higher than USD 2 and 4 million, all lower than NGC’s constraints (15% and 5%, respectively).

These reference results would suggest that NGC’s optimal decision that satisfies its two constraints and has the lowest cost is to continue with the current policy. But this conclusion may change if one assumes that climate change is having an impact on weather-related risk, and that some control measures may be adopted to reduce this weather-related risk. Before assessing whether this is the case, it is worth studying the sensitivity of the reference results to the input values.

¹³ This example highlights why only large oil companies can face the prospect of operating under a “no insurance” policy [15].

5.3 Sensitivity analysis

A sensitivity analysis helps to identify the most "critical" inputs to the model: results are expressed in terms of a rank correlation coefficient between the selected output variable and the samples for each of the input distributions. The higher the correlation between the input and the output, the more significant the input is in determining the output's value.

Exhibit 10 shows that, for the “no insurance”, “offshore” and “earthquake” categories, the input frequency and value distributions play the leading roles. Note that the total cost of insurance is not any more sensitive to the earthquake’s distributions in the cases of options A and C. This reflects the fact that the insurance policy *covers* for these losses. By contrast, since deductible levels for the “offshore platform” risk category are rather high for policies A and C (Table 5), the total insurance cost remains very sensitive to these input variables. The fact that the sensitivity to the input value distribution of category “offshore platform” is higher in option C than in option A reflects the fact that the deductibles in the former case are 5 times larger than the ones in the latter case.

This sensitivity analysis quantifies in mathematical terms the relative roles of deductibles: NGC should focus on reducing the amount of deductibles for events in the “offshore platform” category if it wants to strike a better deal.

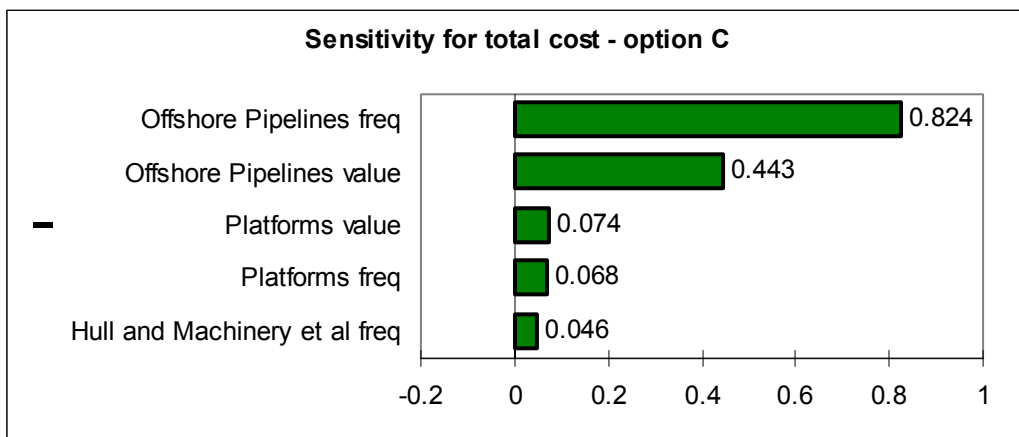
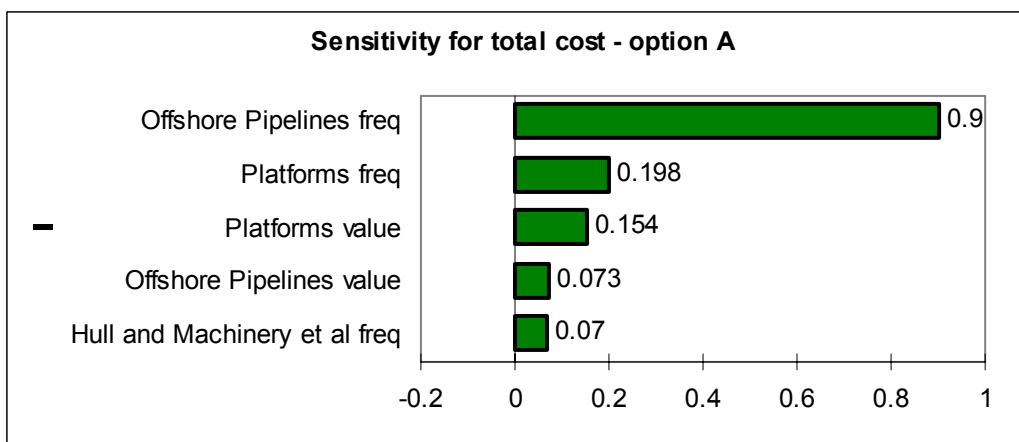
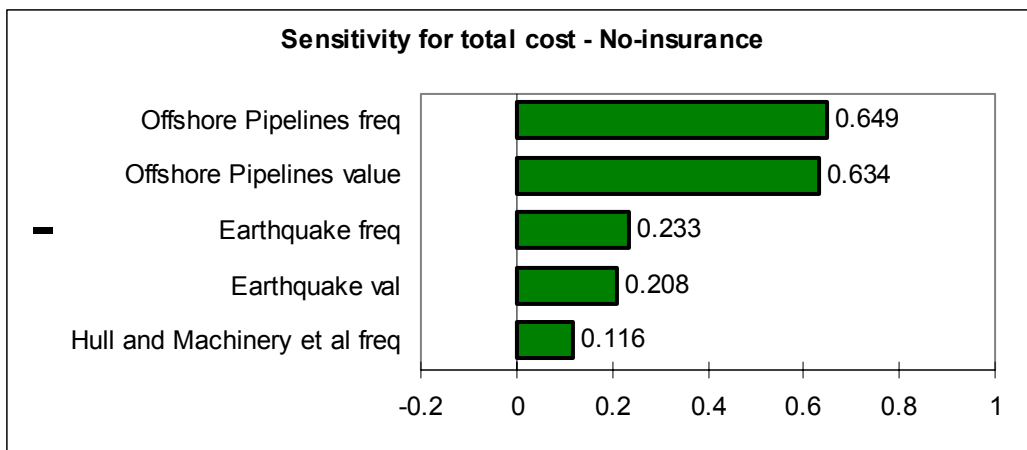


Exhibit 10. Sensitivity analysis of total cost of insurance for the “no insurance” policy (top), and insurances with deductible options A (middle) and C (bottom).

6 Risk's variations due to climate change and the implementation of "control measures"

NGC's executives are concerned that potential losses may be affected by climate change (Appendix D), since events that can cause damages classified in risk categories "platforms", "wind storms" and "hurricanes" may become more frequent and more severe. To analyze the sensitivity of NGC's total losses to climate-induced risk variations, the frequency and the intensity of the losses in these three categories have been gradually increased by 7.18% each year: the next effect of this trend is to double the average frequency and the average damage per event at year 10 (these assumptions are in line with recent scientific conclusions [6, 7]). NGC's management has also the option to implement some "control measures" that could reduce the average damage per event by about 15%, either starting next year or later (more specifically, the option of starting this implementation in year 4 will be considered). To decide which policy to subscribe and whether to implement these control measures, four scenarios have been considered:

- "REF", the reference scenario discussed in section 5
- "HOT", a scenario with double frequency and average loss values¹⁴
- "HOT with control measures", defined as the "Hot" scenario plus implementation of control measures in year 1
- "HOT with delayed control measures", defined as the "Hot" scenario plus implementation of control measures in year 4

¹⁴ A sensitivity analysis has indicated that an increase in severity has a stronger impact on the probability of total cost exceeding large values: this result confirms the indications from the published literature that

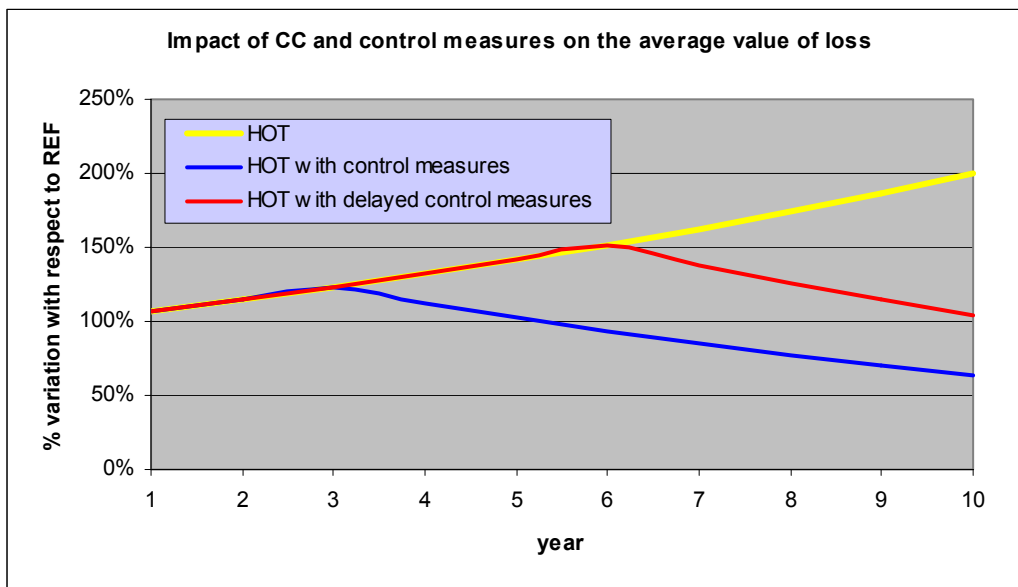


Exhibit 11. Relative impact of climate change (CC) and of control measures on the average value of losses for the “Hot”, “Hot with control measures” and “Hot with delayed control measures” scenarii, computed with respect to the “Reference” scenario.

The relative impact of climate change and of these counter-measures on the average value of losses is shown in Exhibit 11 (the relative impact of climate change on the frequency of weather-related events is the same as the impact on the average value of losses, not shown).

Model simulations indicate that climate change and the adoption of the control measures do indeed change the results. For example, results indicate that in all the three hot scenarii (“hot”, “hot with control measures” and “hot with delayed control measures”), the probability of total losses exceeding USD 2 million in insurance options “current”

climate change may increase substantially the loss due to very few, extreme events, although it may have a small impact on the expected (i.e. average) loss value.

and “A” is higher than 15% (not shown). Therefore, these two options have to be excluded.

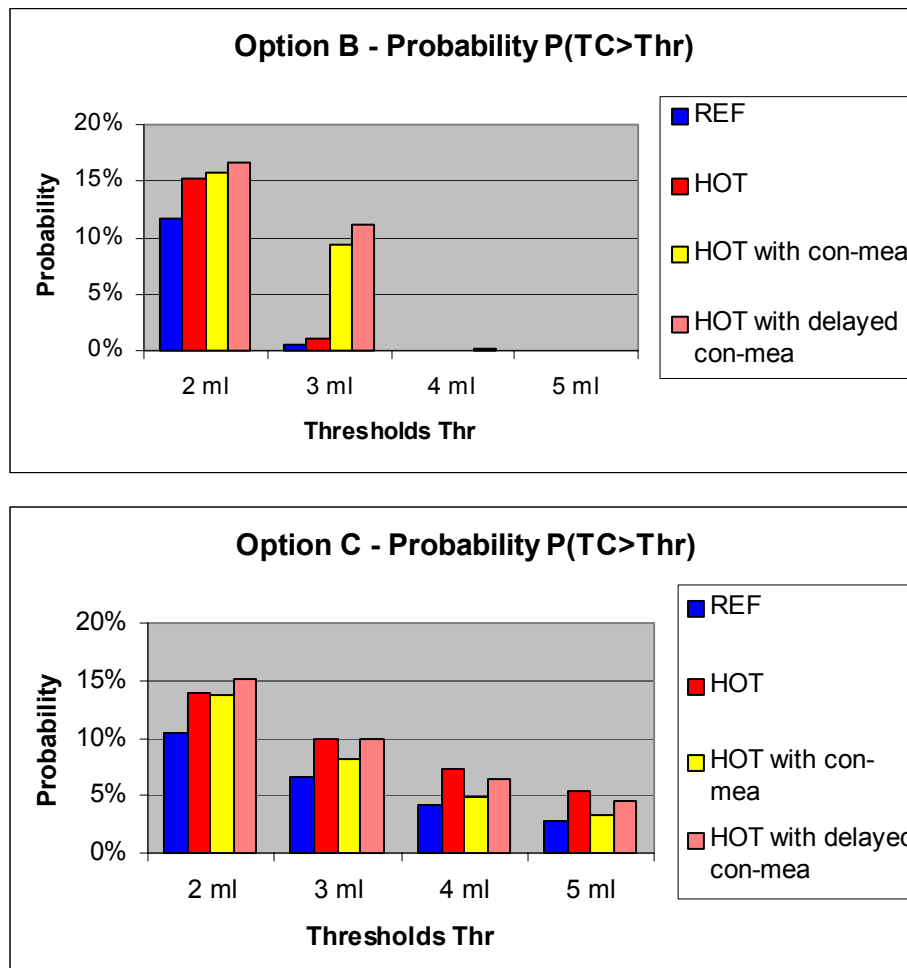


Exhibit 12. Impact of risk variations due to climate change and the adoption of control measures on the probability that the total cost of insurance exceeds 5 thresholds, for insurance options B (top) and C (bottom). See text for details.

Exhibit 12 shows the impact on the probability that the total cost of insurance exceeds value thresholds ranging from USD 1 to 5 millions, for the two remaining possible insurance options, “B” and “C”. Note that the immediate implementation of control measures drastically reduces the impact of climate change on NGC’s future losses, but that a 4-year delayed implementation would severely reduce the mitigation effect of

these measures. Results shown in Exhibit 12 indicate that in a hot climate scenario only “option C” with immediate control measures is associated with probabilities of occurrence of losses higher than USD 2 and 4 millions that satisfy NGC’s constraints. Note that delaying the implementation of the control measures would exclude “option C” as a possible solution to the problem. Tables 8a-c summarize some key results.

<i>Maximum loss</i>	<i>no insuancer</i>	<i>current</i>	<i>option A</i>	<i>option B</i>	<i>option C</i>
REF	29,536,092	1,043,155	2,032,469	3,779,656	6,150,446
HOT	44,197,292	2,209,865	2,821,014	3,904,682	6,295,651
HOT with control measures	38,915,617	1,200,502	2,000,000	3,239,718	5,749,125

Table 8a. Potential impact of climate change on the potential maximum loss. Orange boxes identify options with potential maximum losses higher than USD 6 million. The green bow identifies the only feasible option in a hot, riskier climate.

<i>P(TC>2,000,000)</i>	<i>no insurance</i>	<i>current</i>	<i>option A</i>	<i>option B</i>	<i>option C</i>
REF	10.0%	0.2%	13.0%	11.7%	10.4%
HOT	14.6%	0.5%	16.1%	15.2%	13.8%
HOT with control measures	12.9%	39.9%	17.6%	15.8%	13.8%

Table 8b. Potential impact of climate change on the probability that total insurance costs could exceed USD 2 million. Orange boxes identify options with $P(TC>2ml)>15\%$. The green bow identifies the only feasible option in a hot, riskier climate.

<i>P(TC>4,000,000)</i>	<i>no insurance</i>	<i>current</i>	<i>option A</i>	<i>option B</i>	<i>option C</i>
REF	4.1%	0.0%	0.0%	0.0%	4.2%
HOT	7.6%	0.0%	0.0%	0.0%	7.3%
HOT with control measures	4.9%	0.0%	0.0%	0.1%	4.9%

Table 8c. Potential impact of climate change on the probability that total insurance costs could exceed USD 4 million. Orange boxes identify options with $P(TC>4ml)>5\%$. The green bow identifies the only feasible option in a hot, riskier climate.

It is now possible to answer the third and the fourth questions posed by NGC executives to Sigma Risk.

- Q3. The answers to questions 1 and 2 change in a “hot climate scenario”. Table 8 contrasts the potential maximum total loss, and the probabilities that the total cost of the insurance will be higher than USD 2 and 4 million in the “reference”, “hot” and “hot with control measures” scenarios. In a hot scenario, only insurance “option C” associated with the immediate implementation of control measures satisfies all three NGC’s constraints and should be considered for renewal.
- Q4. NGC must implement the planned “control measures” as soon as possible, i.e. by starting any required implementation works in year 1: delaying the implementation to year 4 would increase the probabilities of high losses to unacceptable levels.

In conclusion, the solution of NGC’s problem under the assumption that climate change is increasing the severity of weather-related losses, is that NGC should renew its insurance policy in option C and start implementing the planned control measures in year 1.

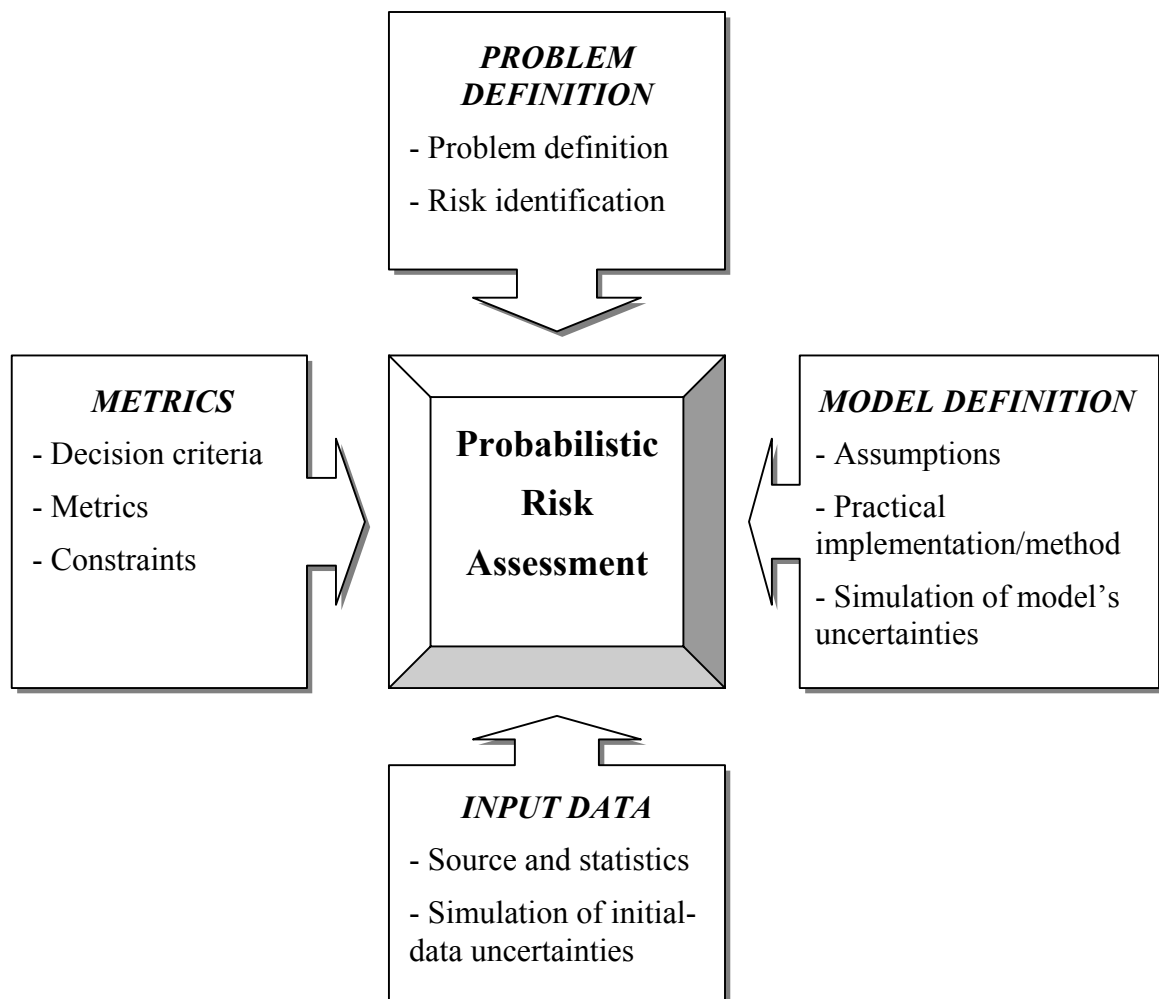
7 A generalized framework to manage uncertainty in risk assessment

The first general conclusion that can be drawn from the business case discussion is that a probabilistic approach is more valuable than a deterministic one, since it provides a more complete view of the possible future scenarii.

The second general conclusion refers to the process that a probabilistic risk assessment approach involves. The analysis of the NGC's business case has shown that it comprises four key elements:

- The definition of the problem and of the decisions that need to be taken
- The definition of the measures associated with the decision process
- The definition of the input data
- The construction of the simulation model

This is schematically illustrated by the Probabilistic Risk Assessment framework, shown in Exhibit 13, which has been designed to include the key elements of the process. The four elements are all necessary to define the process: changing any of them will change the overall definition problem and thus affect the final outcome. For example, consider the decision criteria and the selection of the assessment metrics (i.e. the measurement systems that are used to compare different output scenarii and to take the final decision): changing them re-defines the problem, and may lead to completely different final decisions.



*Exhibit 13. The key stages of the **Probabilistic Risk Assessment** framework.*

The application of this newly defined Probabilistic Risk Assessment framework should help to approach in a correct way any decision process. Apart for risk assessment problems, as it was illustrated in this report, results published in international literature suggest that this framework captures the key elements required to solve problems in weather prediction [2], energy demand forecasting [17] and finance [7].

Acknowledgements

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Appendix A - Taxonomy of offshore insurance policies

Offshore insurance policies can be classified in the five categories [14]:

- A “Physical Loss or Damage” policy, to insure the company and any contractor against accidental damage, such as fire, lightning or explosion, to first party property.
- A “Third Party Liability” policy, to cover third party property damage, bodily injury (this may also include damages due to exposure to materials such as asbestos) and contractual liabilities.
- An “Operator’s Extra Expenses” policy, to cover the cost of controlling a well following a blowout¹⁵, plus the expenses of re-drilling, clean-up operations and pollution.
- A “Business Interruption” policy, to cover for reduced earnings due to damage to its property.
- A “Political Risks” policy, to be protected against risks such as war and confiscation.

The most comprehensive policy, which provides coverage against any loss, is called an “All risks” policy. This is the policy subscribed by NGC.

¹⁵ A blowout is defined as an uncontrolled flow of gas, oil or other well fluids. It is potentially the most dangerous event that can occur in an oil or gas well. The majority of low-outs are caused by human error.

Appendix B – NGC’s 1996-1998 financial statement and investments

Income Statement			
(1996) USD\$ ('000)	1998	1997	1996
Sales	362,810	373,157	351,182
COS	- 338,257	- 282,265	- 242,915
Gross profits	24,553	90,892	108,267
Net operating costs	- 23,323	- 18,510	- 22,720
Operating profit/loss	1,230	72,383	85,547
Interest and investment income	6,239	6,252	10,058
interest expense	- 5,328	- 2,371	- 2,771
Other income	8,488	10,667	20,230
Profit before taxes	10,629	86,931	113,064
Taxation	- 7,409	- 28,009	- 50,919
Net profit	3,221	58,922	62,145
Balance Sheet			
Net current assets	151,998	162,045	121,120
Join venture facilities	-	3,660	3,626
Long-term loans and investments	84,090	67,022	63,279
Fixed assets	199,289	158,605	113,766
Pension assets	-	-	-
Deferred items	-	-	-
	435,377	391,332	301,791
Long-term debt and advances	96,502	75,245	32,297
Deferred items	62,853	35,468	24,875
Minority interest	3,765	3,884	3,977
Shareholder equity:	-	-	-
Share capital	40,128	40,128	40,128
Capital reserves	24,454	35,943	39,650
Retained earnings	207,676	200,664	160,866
	435,377	391,331	301,791

Table B.1. NGC’s 1996-1998 financial statements [9, 10].

NGC has a diversified equity investment portfolio that comprises:

- 100% shareholding in the National Energy Corporation of T&T Ltd (NEC), which has significant port and marine facilities.
- 100% shareholding in NGC T&T Liquefied Natural Gas Company Ltd (LNG), which has a 10% stake in Atlantis LNG, the company formed to develop the country's first liquefied natural gas plant, which was completed in 1999.
- 83% shareholding in the La Brea Industrial Development Company, which is the company charged with the development of an industrial estate and port at La Brea, in south Trinidad.
- 51% shareholding in Phoenix Park Gas Processors Ltd, a gas processing plant with the capacity to extract 33,500 barrels per day of natural gas liquids.
- 20% equity interest in TRINTOMAR, a locally-owned marine gas production company operating out of the Pelican Field.
- 18% shareholding in National Helicopter Services Limited, which provides helicopter transportation services to and from the offshore installations.

Appendix C – The Monte Carlo-based risk assessment model

Model assumptions:

- The frequency distributions defines the number of events that will occur in the forthcoming 10 years: the distributions are Poisson functions $P(\lambda_j)$ defined in terms of the mean parameter λ_j
- The value distributions define the loss amount for each event: the distributions are log-normal functions $LN,(\alpha_j,\beta_j)$ defined in terms of the mean and standard deviation parameters (α_j,β_j)
- There are $J=6$ risk categories, each characterized by a different set of parameters

Denote by f_j , with $j=1,6$, the set of random samples from the J frequency distributions. These numbers give the number of events for each category that will occur in the forthcoming years (e.g. if $f_j=2$, than this event is assumed to occur for 2 years). For each year $k=1,10$, if the j -th event occurs than the loss value $v_{j,k}$ is sampled from a log-normal distribution $LN(\alpha_j,\beta_j)$. The j -th category total loss is then computed as the sum of all these values.

For each category j , denote by V_j the 10y total loss and by D_j the 10y total deductible. Denote also by TL the 10y total loss, by CI the cost of insurance and by TC the total cost of insurance (i.e. the sum of total value of the self-insured loss plus the cost of the insurance).

Schematically, the model can be written as:

```

begin
  Define the input parameters that define the input distributions  $\lambda_j, \alpha_j, \beta_j$ 
  Define the deductibles  $D_j$ 
  for year  $k=1,10$  do
    for category  $j=1,J$  do
      sample  $f_j \in P(\lambda_j)$ 
      if  $f_j \geq k$  then
        sample  $v_{j,k} \in LN_k(\alpha_j, \beta_j)$ 
        update value  $V_k = V_k + v_{j,k}$ 
      end if
    end for
    add costs due to control measures  $V_k = V_k + CM_k$ 
    discount costs  $V_k = V_k \cdot PV_k$ 
    update total loss  $TL = TL + V_j$ 
    compute self-insured loss  $SI_j = \min(V_j, D_j)$ 
    update total self-insured loss  $SI = SI + SI_j$ 
  end for
  compute total cost of insurance  $CoI = TL + SI$ 
stop

```

This model has been coded in Excel and solved with a Monte Carlo method using @RISK. The input distributions have been defined using @RISK Poisson and lognormal functions, and all simulations have been generated using 10,000 iterations. In the simulation, the discount rate has been assumed to be 10%. It has also been assumed that average losses' values are increasing by 10% per year. The cost of control measures has been assumed to stay at a nominal value of USD 200,000 per year, for 3 consecutive years. Table C.1 shows the @RISK model when run in the “Hot with control measure” scenario.

Table C.1. @RISK Monte Carlo model

Table C.1. @RISK Monte Carlo model

Appendix D - Climate change

Scientific studies begin to show that the world climate is likely to undergo small but significant changes in temperature and precipitation levels in the coming decades, and the impact of weather and climate on human and business activities may become substantial. In fact, during the past 50 years the issue of the potential impact of climate change on human activity has become increasingly important for two main reasons: firstly, scientific advances have improved the understanding of the dynamics of the earth system (atmosphere, ocean and land, [5, 6]) and, secondly, human activities have become increasingly more vulnerable to severe weather.

If we consider the US, a country for which a reliable data-set of recorded weather losses is readily available, we see that an average of \$16 billion in losses is incurred annually for weather related damages [3, 4, 8, 12, 13], with losses peaking at about \$60 billion (Exhibit D.1). But not only have average damages been increasing, more worryingly weather related losses and damages linked to single, extreme weather conditions are increasing. In the summer of 1993, for example, severe flooding due to persistent heavy rain and thunderstorms affected the central US (estimated losses ~\$22 billion). In 1998, first a severe draught and heat wave hit Texas, Oklahoma and the Carolinas (estimated losses/damages of \$9 billion), then hurricane Bonnie struck Carolina and Virginia (estimated losses/damages of \$1 billion) and finally, hurricane George caused disruption in Louisiana, Mississippi and Alabama (estimated losses/damages of \$6 billion).

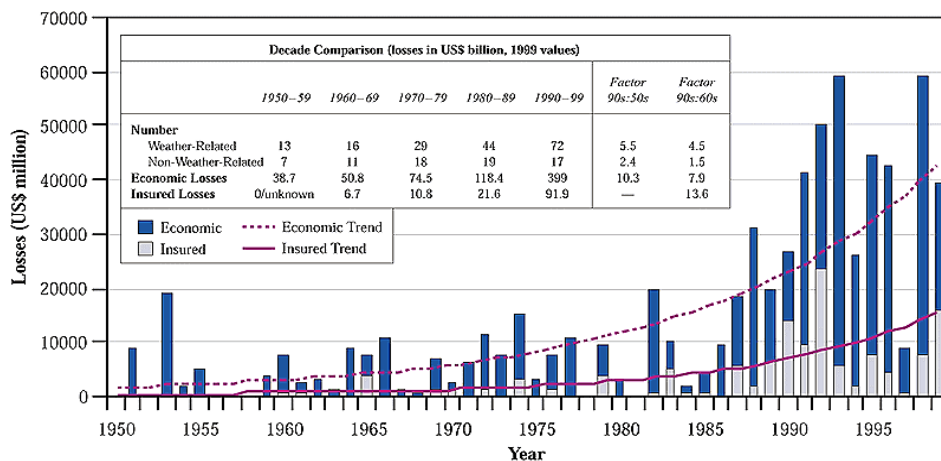


Exhibit D.1. US weather related losses (source IPCC 2001).

The Intergovernmental Panel on Climate Change [5, 6] presents comprehensive evidence that regional climate changes have already affected many biological and physical systems, and discusses projected climate changes and predicted changes in average temperatures (Exhibit D.2). Accordingly to the IPCC, impacts are already evident on ocean circulation, sea level, air quality, productivity of the natural ecosystem, geographical distribution, behaviour of plants and animal species, food, energy, water supply, health, and in general on human wealth fare.

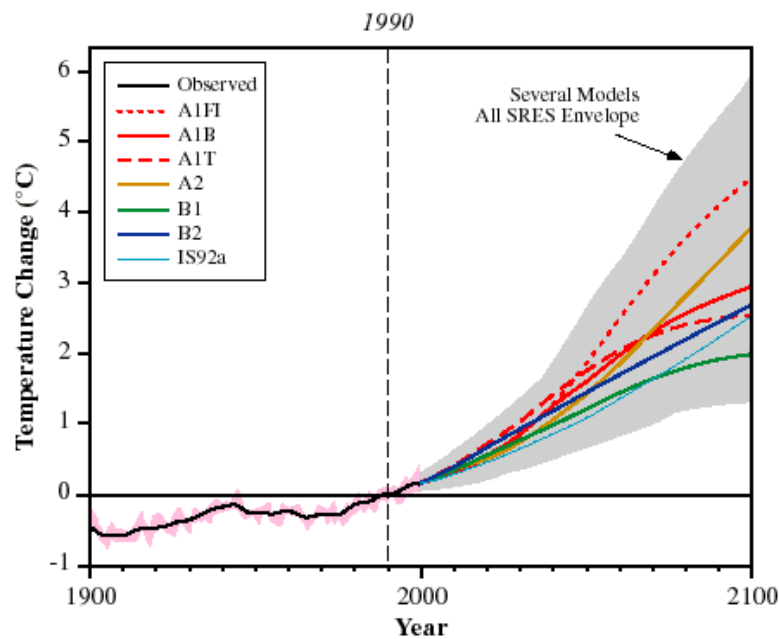


Exhibit D.2. Projected impact of climate change on global average temperature (IPPC 2001).

Climate change is expected to increase both the frequency of extreme weather events, and their severity: due to the complexity of the atmosphere/earth's/ocean system, it is still difficult to quantify the potential impact, but an increase of a factor of 2 in certain regions is to be considered a possibility. In fact, while the average impact of climate change may be small, the local effect can be large: certain countries could even benefit from the rise of temperatures, but others will suffer, especially countries that have less resources to devote to adaptation policies. Although the overall economic impact of climate change is very uncertain, there is consensus on the fact that understanding it is one of the challenges on the 21st century [5, 6, 11].

Appendix E - Original Management Report proposal

One of the key difficulties in risk-assessment and project valuation is modelling uncertainties. Monte-Carlo based simulation methods can be used to assess the costs and benefits of alternative managerial decisions: one of their key advantages is that they are able to provide not only the most-likely scenario but also probabilities of rare but potentially very damaging events. This probabilistic, as opposed to single, deterministic, information is extremely valuable in sectors such as insurance.

In this report, a Monte-Carlo based approach will be applied to the case of a consulting firm advising a gas corporation on the level of insurance coverage that it should negotiate against catastrophic losses linked to low frequency, high impact natural events. This is a very relevant problem for the risk-consulting firm, since it represents a typical core-business case. Thus, reaching a solution following this new approach will provide the consulting firm with new insights into how similar projects can be evaluated in the future.

The two key objectives of the report will be: to review state-of-the-art techniques that can be used to approach similar problems, and to provide a solution of the case study. The report will be structured into two main parts, the first reviewing the theory and the second discussing the case study. The report is thus expected to discuss how Monte-Carlo based methods can be used to solve similar valuation problems and to provide a solution to the case presented.

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