Risk Scaling – A Market-based Approach

Submitted by Pacific Gas & Electric Co. (PG&E), in R.20-07-013, Phase 3.

Introduction

In R.20-07-013 (Order Instituting Rulemaking to Further Develop a Risk-Based Decision-Making Framework for Electric and Gas Utilities), the Assigned Commissioner's Phase 3 Scoping Memo and Ruling Extending Statutory determined that the issue of Risk Scaling (formerly, Risk Attitude) to be in the scope of Phase 3. More specifically, the Scoping Memo directed that "discussions … should focus primarily on changes in parties' previous comments on this topic in light of the significant refinements to the RDF *(Risk-based Decision-Making Framework)* adopted in D.22-12-027," and that they "… should address the question of whether the Commission should identify best practices for risk scaling or adopt minimum requirements…"

With D.22-12-027, the Commission adopted a Cost-Benefit Approach to Risk Assessment, whereby risks and risk-reduction benefits are assessed in dollars, where previously they were assessed in "unitless Risk Scores." An important component of the monetization framework is the Risk Scaling (Attitude) Function, defined to be:

> A function or formula applied to Monetized Levels of an Attribute to express the attitude towards uncertainty, i.e., risk aversion, neutrality or seeking. (Risk Attitude Function at D.22-12-027 Appendix B, p. A-4)

The proposal herein is the result of the Commission's decision to require IOUs to, simply stated, put a price on Risk. In response, PG&E's suggestion is to adopt the *market* price of the Risk. Insurance and Capital Markets price risk as a matter of course; the Risk Scaling Function can be used in conjunction with prices from these industries to reflect market, hence societal, attitudes towards risk.

This approach comes with distinct advantages that will be discussed in the Reasons for Recommendation section below. The conceptual framework that forms the basis of this proposal, the Fundamental Theorem of Asset Pricing/risk-neutral *probability measure* (not to be confused with a risk-neutral *attitude*) is a cornerstone of modern financial valuation and is discussed in the context of the Risk Scaling Function. An implementation example is provided and extensions to incorporate Environmental and Social Justice (ESJ) priorities are also discussed below.

Considerations and Principles

Throughout the history of the R.20-07-013, the issue of comparability of Risk scores has been raised on multiple occasions. For example, in the Assigned Commissioner's Phase II Scoping Memo and Ruling Extending Statutory Deadline in R.20-07-013, the question was posed:

> Should the Commission consider requirements, methods, milestones and timeframes to develop comparable risk scores and/or comparable risk spend efficiency scores across IOUs?

By adopting the Cost-Benefit Approach, the Commission, participants and interested parties at large have a common measure of Risk that is familiar, intuitive, and makes big strides towards comparability. D.22-12-027 Findings of Fact 5 further affirmed that "Dollar valuation of risks is common practice in risk assessment across various industries." Hence the RDF is now firmly in place to ask and answer the logical follow-on questions:

- Should RDF-based Risk pricing (i.e., scores) be comparable across other *sectors and industries*?

- How should the prices developed by IOUs to assess Risk be consistent with how the Insurance and Capital Markets are pricing those same (or similar) Risks?

Closely related, concerns have been raised throughout PG&E's RAMP and GRC about the transparency and objectivity of how its prior Scaling Function was developed. The issue is in large part due to expressing risk in Unitless Risk Scores, an approach only utilized in the Settlement Agreement and not in industry at large, which makes transparency and commonality difficult. Using dollars as a risk measure does the opposite. Therefore, a consideration for any Risk Scaling Function in the Cost-Benefit Approach is whether it is based on transparent and objective data and methods.

Another consideration, as documented in the Phase 3 scoping memo is that it should be clear whose "perceptions of risks should be reflected in the chosen risk scaling function – the IOU's, ratepayers, or some subset of ratepayers".

Finally, as a general principle, Risk Scaling Functions should *not* be risk-seeking. IOUs should not be led or encouraged by the RDF to undervalue or underestimate Risks, particularly safety related risks, by downplaying or discounting expected consequences to customers, or catastrophic tail events that may not be well represented by expected values using the original distribution.

Recommendation

In light of the discussion above, PG&E recommends that the Commission find reasonable, among other potential approaches, a market-based approach to developing Risk Scaling Functions such that the Function(s):

1. Does not lower the expected monetized value of the Attribute levels.
2. Notwithstanding the above, results in values consistent with prices and/or estimates from risk transfer markets, and/or public policy towards risk transfer<u>, to the extent such pricing is applicable and available</u>.

To reflect the principles above, specific modifications to the RDF are suggested below.

RDF Modifications

Step 1A, No 7 of the RDF can be modified to recognize a market-based approach, as follows.

- Step 1A, No. 7. Cost-Benefit Approach Principle 6 – Risk-Adjusted Levels.

7.	Cost-Benefit Approach Principle 6 – Risk-Adjusted Levels	Apply a Risk Attitude Function to the Monetized Levels of an Attribute or Attributes (from Row 6) to obtain Risk-Adjusted Levels. The Risk Attitude Function specifies attitude towards different kinds of Outcomes including capturing aversion to extreme Outcomes or indifference over a range of Outcomes. The Risk Attitude Function can be linear or non-linear. For example, the Risk Attitude Function is linear to express a risk-neutral attitude if avoiding a given change in the Monetized Attribute Level does not depend on the Attribute Level. Alternatively, the Risk Attitude Function is non-linear to express a risk-averse or risk-seeking attitude if avoiding

		a given change in the Monetized Attribute Level differs by the Attribute Level. Evidence-based approaches can also be considered, such as, but not limited to, a market-based approach where applicable, that: 1. Does not result in Risk-Adjusted Values lower than the expected monetized value of the Attribute levels. 2. Notwithstanding the above, results in values consistent with prices and/or estimates from risk transfer markets, and/or public policy towards risk transfer, to the extent such pricing is applicable and available.

Reasons for Recommendation

Regarding Recommendation Item 2 above, PG&E's approach, at its core, is to use available, objective data to determine the Risk Scaling Function(s). Prices from Insurance and Capital Markets meet these criteria because they are for products from independent entities that mitigate the same underlying Enterprise Risks that an IOU faces: wildfires, loss of containment on gas pipelines, cyberattack, etc. These prices encode preferences. As such, they can be used to develop empirically based Risk Scaling Function(s) that will be more insightful and representative than any approach considered to date.

The market-based approach creates consistency and alignment. The Commission already oversees PG&E's Insurance and Capital Markets activities; therefore creating a tie between the RDF and Insurance and Capital Markets would create consistent and complementary policies and decisions. The Commission, and IOUs can look to the markets to assist in ascertaining the value of mitigations (i.e., the efficient allocation of capital). As mitigation programs are deployed, the amount of risk is reduced, which all other things being equal, would reduce the premiums demanded by insurers and other market participants.

Market theory tells us that the prices obtained from a perfect market maximize value to society. Of course, no market is perfectly competitive, complete, or truly representative of societal preferences (for instance, in addressing ESJ concerns), but there are established practices that can be employed within the market-based approach to account for shortcomings while still preserving its function of communicating societal values. Hence, Risk Scaling Function(s) developed to be consistent with market prices would represent societal risk preferences, not the IOU's.

Known Concerns with the Market-based Approach

The availability of reliable market price information is generally the largest issue associated with such an approach. Markets might not exist or be too thinly traded to be able to infer much information from them. To address this issue, PG&E suggests that in addition to adopting published prices from existing sources, market participants (brokers, insurance companies, re-insurance firms, etc.) can be consulted and surveyed on a regular basis (e.g. annually) to identify and determine the scope, validity and relevance of information. Extending this suggestion further, commercial arrangements can be developed with independent consulting firms to perform these activities on behalf of the IOUs, or the Commission.

Transparency as to how market prices are applied is also a concern. However, the RDF already requires IOUs to "specify all information and assumptions that are used …", and that "(t)he methodologies used

… should be mathematically correct and logically sound. The mathematical structure should be transparent."[1] Therefore, IOUs are already expected to be clear in their application of the data. Indeed, in the implementation example below, PG&E describes the information used, economic principles applied, and the mathematical structures employed, thereby demonstrating how transparency can be achieved.

Markets generally demand risk premiums (defined as the amount over the expected price); however, it is conceivable that there might be periods of pricing inefficiencies, lack of data, market distortions, etc., leading to situations that suggest that riskier assets would be priced lower than ones with less risk. Scaling Function(s) derived from such prices would imply a risk-seeking behavior. Recommendation Item 1 serves purely as a safeguard against such situations, ensuring that the general principle that Risk Scaling Functions should not be risk-seeking, is always maintained.

Background

The RDF expresses risk as the product of the Likelihood of a Risk Event (LoRE) multiplied by the Consequence of a Risk Event (CoRE),

Risk (in $) = LoRE x CoRE (in $)

The RDF, D.22-12-027 Appendix B, provides guidance on CoRE as follows:

- An Attribute is defined as "an observable aspect of a risky situation that has value or reflects a utility objective, such as safety or reliability. *Changes in the Levels of Attributes are used to determine the Consequences of a Risk Event* …" (Definitions, Attribute at p.A-2)
- Row No. 5 of Step 1A (Cost-Benefit Approach Principle 4 – Risk Assessment), states "(w)hen Attribute Levels that result from the occurrence of a Risk Event are uncertain, assess the uncertainty in the Attribute Levels by using expected value or percentiles, or by specifying well-defined probability distributions, from which expected values and tail values can be determined.
- Row No. 6 of Step 1A (Cost-Benefit Approach Principle 5 – Monetized Levels of Attributes) follows and directs IOUs to "(a)pply a monetized value to the Levels of each of the Attributes using a standard set of parameters or formulas …".
- Row No 7. of Step 1A (Cost-Benefit Approach Principle 6 – Risk-Adjusted Levels) further directs IOUs to "(a)pply a Risk Attitude *(Scaling)* Function to the Monetized Levels of an Attribute or Attributes (from Row 6) to obtain Risk-Adjusted Levels. The Risk Attitude *(Scaling)* Function specifies attitude towards different kinds of Outcomes including capturing aversion to extreme Outcomes or indifference over a range of Outcomes …"
- Row No. 24 of Step 3 (Use of Expected Value for CoRE; Supplemental Calculations), "(t)he utility will use expected value for the Cost-Benefit Approach-based measurements and calculations of CoRE …"

To summarize, to obtain a value for the CoRE, start with a probability distribution of losses in natural units (e.g., Equivalent Fatalities), convert this distribution to dollars, apply the Risk Scaling Function, and take the expected value (in $) of the resulting distribution.

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[1] D.22-12-027 Appendix B, Global Items, Row No. 29, Transparency in RAMP and GRC – Results can be understood at p.A-21.

Risk Scaling - An Alternative Treatment

RDF Row No. 7 of Step 1A, as described above, describes in some detail that the Risk Scaling Function can be used to express “risk preferences.” This in turn has led to esoteric discussions and heated debates about what “risk preferences” are, both conceptually and mathematically, and what kinds of “preferences” should be applied in the RDF. A more productive line of reasoning starts with stating the purpose of the Risk Scaling Function in simpler, purer terms: *it is a mathematical function that converts one probability distribution into another*.

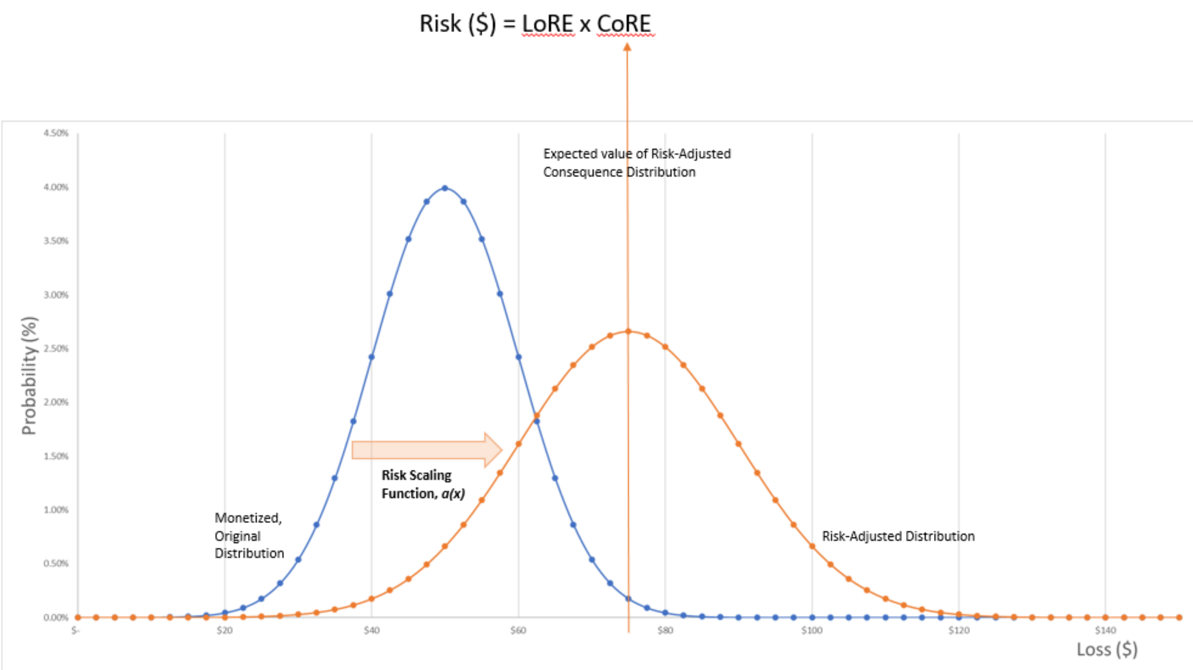

Figure 1 – Illustrated steps to obtain CoRE, highlighting the Risk Scaling Function

Implied Probability Measures

In the context of Figure 1 above, discussions to date have proceeded in a roughly left to right manner. Assuming a certain monetized original distribution, i.e., a distribution of historical losses in natural units (e.g., Equivalent Fatalities) converted into dollars using a Value of Statistical Life, what Risk Scaling Function *a(x)* should be applied? Why should it be applied and have a particular functional form (linear, quadratic, etc.), and what is the justification for the parameter values (slopes, etc)? What is the resultant Risk-Adjusted distribution?

PG&E’s approach takes a different tack by coming at Figure 1 from both directions. Is there a “target” (i.e., risk-adjusted) distribution (or parts of it), different from the original, that can be inferred or *implied* from observed data? If so, then an *a(x)* can be developed that transforms the monetized original distribution into the “target.”. Hence the Risk Scaling Function is developed in a data-driven manner.

Market-Implied Probability Distributions

Probability theory and distributions are often used in a “frequentist” context, i.e., how often monetary losses of various sizes have occurred based on the historical record. However, the requirements for a probability *measure*, the basis of probability theory, are that for any potential outcome (e.g., a loss of $500), (i) a value between 0.0 and 1.0 (inclusive) can be assigned, (ii) the values from mutually exclusive outcomes are additive, and (iii) that the sum of the values over all outcomes is 1.0. Any such system that meets these basic requirements can be considered a probability measure. Hence probabilities can be used to encode a set of preferences or forecasts of the future.

Consider, with no loss of generality[2], there is a primitive tradeable contract that obligates the underwriter to pay $1 if wildfire losses over the next season are greater than $125 million. What would the underwriter of such a contract charge? Since the contract pays out at most $1, its price would not be more than $1. Furthermore, since the underwriter is taking on a liability, the price would not be negative. In this simple case, it is obvious that the contract can be re-expressed as a probabilistic statement, leading to an implied probability of P[wildfire losses > $125m] = Price of contract.

The market price or probability represents the consensus belief or forecast of its participants. More generally, the Fundamental Theorem of Asset Pricing[3] states that the presence of arbitrage-free markets implies the existence of special probability measures, called *risk-neutral probability measures*. As stated above, these are *not* the same as a risk-neutral preference, but rather they are probability measures determined from markets under which participants can behave *as if they were risk-neutral*.

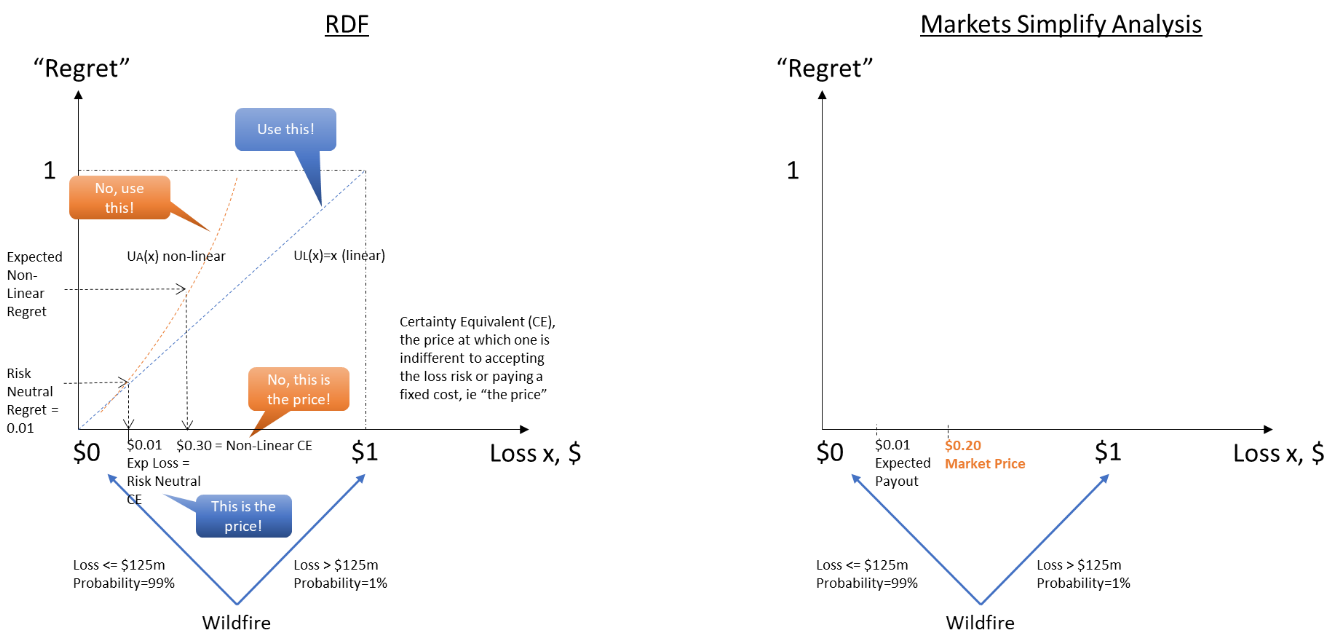

Figure 2 Markets take the debate out of which prices to use

[2] The example does not consider interest-rates/discounting, which is accounted for in the general theory.

[3] Delbaen, Freddy; Schachermayer, Walter. "What is … a Free Lunch?". Notices of the AMS: Volume 51 Number 5, p.526; https://www.ams.org/notices/200405/what-is.pdf

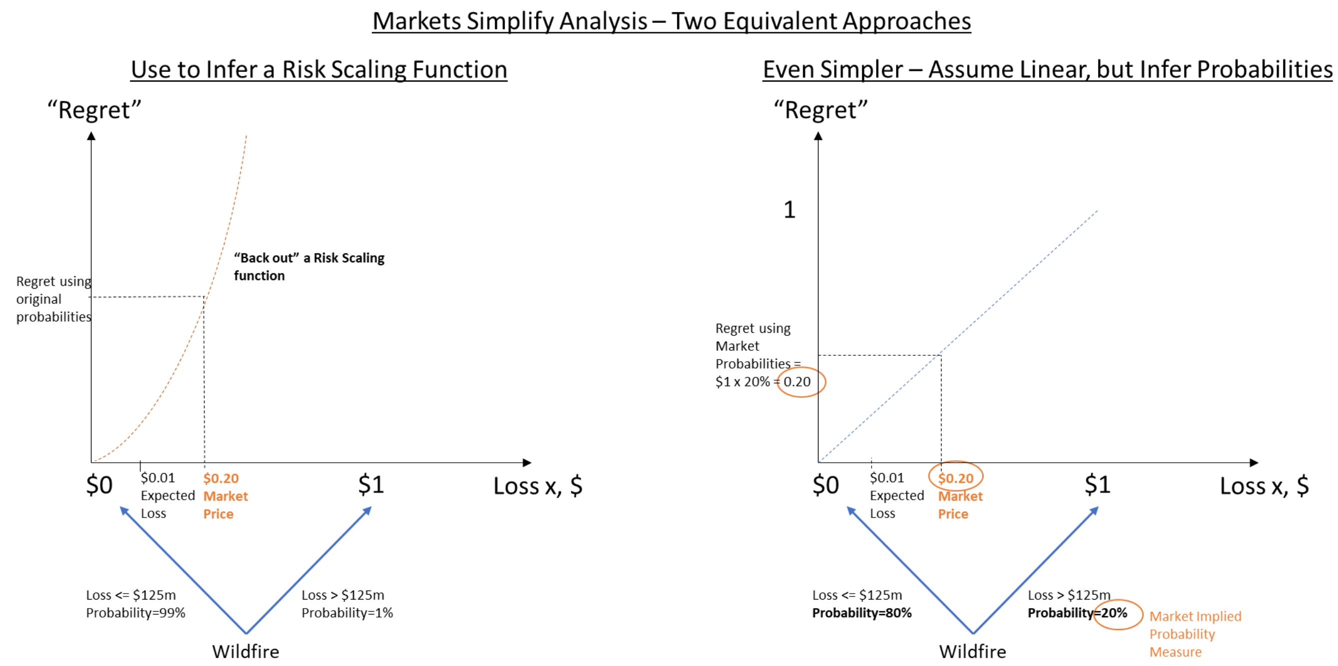

Figure 3 The use of market prices can be viewed in two ways

Implementation Example

The market-based approach is inherently data-driven, where the data being considered are prices for market securities and insurance contracts. Markets are constantly evolving, with new products and transactions not only providing updated results but revealing new information to use in inferring ("backing out") the market-implied distribution. The description below should be considered an illustrative implementation based on a subset of available data and is by no means exhaustive or the only possible method to incorporate a market-based approach.

Catastrophe (CAT) Bonds

The Federal Reserve Bank of Chicago explains that "(a) CAT Bond is a security that pays the issuer when a predefined disaster risk is realized, such as a hurricane causing $500 million in insured losses or an earthquake reaching a magnitude of 7.0 (on the Richter scale)." [4]

A selection of CAT bond issuances related to California Wildfire perils is listed below:

Name	Date of Issuance	Attachment	Coverage	Expected loss	Pricing	Pricing/Expected Loss
PG&E Cal Phoenix Re cat bond	Aug 2018	$1.25B	$200M	1.01%	7.5%	**7.5**
Sempra SD Re Ltd (series 2018-1)	Oct 2018	$1.326B	$125M	0.21%	4%	19

[4] Catastrophe Bonds: A Primer and Retrospective, *Chicago Fed Letter,* No. 405, 2018; https://www.chicagofed.org/publications/chicago-fed-letter/2018/405

Sempra SD Re Ltd (series 2020-1)	July 2020	$1B	$90M	1.52-1.8%	9.75%	5.4-6.4
Sempra SD Re Ltd (series 2021-1) class B	Oct 2021	$1.21B	$135M	1.56-1.85%	9.25%	5-6
LA DWP Protective Re Ltd (series 2020-1)	Dec 2020		$50M	0.64-0.74%	10.75%	15-18
LA DWP Power Protective Re Ltd (series 2021-1)	Oct 2021	$125M	$30M	0.64-0.76%	15%	20-23

A further source of information is the Artemis Catastrophe Bond Deal Directory[5].

To illustrate the basic workings of these securities, in August 2018 (prior to the Camp Fire), PG&E sponsored the first CAT bond to cover Wildfire risk. The bond had an Attachment of $1.25 billion and Coverage of $200 million, i.e., losses between $1.25 billion to $1.45 billion ($1.25 billion + $200 million) were covered by bondholders (investors). Thus, if the total losses were under $1.25 billion, no payments would be made. If the losses totaled $1.3 billion, the bondholders would pay PG&E $50 million ($1.3 billion – $1.25 billion). If the losses were at or over $1.45 billion, the payment would be capped at $200 million (the Coverage level). An independent firm, AIR Worldwide, working with PG&E, assessed the risk (i.e., the cost - what bondholders might have to pay out) to have an expected value of 1.01% of principal ($200 million) or $2.02 million (not including interest on the principal). However, the transacted price was $15 million (7.5% of $200 million), approximately 7.5 times expected losses. The transacted price of the security is the expected price under some probability distribution of losses. In this case, it cannot be the original distribution. Instead, it is the risk-adjusted/risk-scaled/market-implied distribution that makes investors *act* as if they were risk-neutral prices the CAT bond with a 7.5 multiplier premium.

Furthermore, PG&E is not the only entity that transacted in such risk-transfer securities. In October 2021, Los Angeles Department of Water and Power (LADWP; a government agency) sponsored a CAT Bond for Wildfire-related perils with Attachment at $125 million and Coverage of $30 million. The modeled expected loss for such a security was between 0.64% - 0.76% (of the principal, $30 million), but the transacted price was 15%, representing a risk premium of over 20 times the expected losses.

In this implementation example, we will use LADWP's CAT bond (and general market insurance information below) to demonstrate the market-based approach.

The details on LADWP's CAT Bond were presented by Aon Securities, LLC to the California State Senate Insurance Committee on March 17, 2022[6], in Aon's 4Q-2021 Quarterly Report[7] and also described by

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[5] https://www.artemis.bm/deal-directory/

[6] https://sins.senate.ca.gov/sites/sins.senate.ca.gov/files/presentation_by_katie_sabo_for_aon.pdf

[7] https://www.aon.com/reinsurance/getmedia/9b4d72c0-a3ba-413a-b372-2b22b472282c/20220211-ils-q4-update.pdf.aspx

Artemis[8]. For the purpose of this discussion, and with no loss of generality in the overall approach, the bond will be assumed to compensate for losses dollar-for-dollar, beginning above $125m, with payments capped at $30m. The figure below illustrates the payment structure and the mathematical relationship between the original and market-implied distributions.

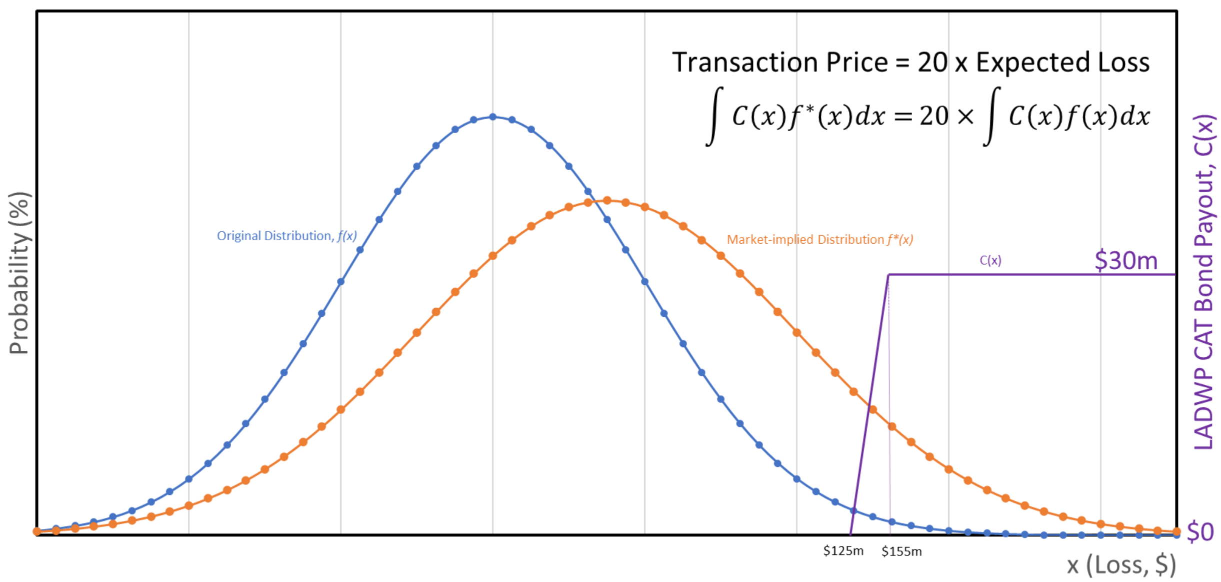


Figure 4 Relationship between Original and Market-Implied Distributions for Simplified LADWP CAT Bond

Insurance Loss Ratios

Insurance Loss Ratios are defined as the total claims against an insurer divided by the total premiums collected. If an insurer collects more premiums than the losses it is obligated to cover, then its Loss Ratio would be less than 100%. This also implies risk aversion as consumers are willing to pay more than the expected losses. The inverse of this ratio calculates the risk premium that insurance companies typically charge customers.

The U.S. Department of the Treasury publishes an Annual Report on the Insurance Industry. The Property and Casualty Sector Combined Loss Ratios from 2017 to 2021 ranged from 59.34% to 62.38%[9]. More generally, ratios have ranged between 50% to 75% implying risk premium multiples of between 1.33 to 2.0.

General Method

To start, a functional form ("shape") for the Risk Scaling Function is proposed. Thus, a function, *a(x, p1, p2, …)* is proposed that takes a loss amount, *x* (in dollars), together with a set of parameters (*p1, p2, …*) and produces a risk-adjusted value (in dollars as well). The idea is to calibrate the parameters such that

[8] https://www.artemis.bm/deal-directory/power-protective-re-ltd-series-2021-1/

[9] Annual Report on the Insurance Industry, Federal Insurance Office, U.S. Department of the Treasury, September 2022, Figure 27: P&C Sector Combined Operating Ratios at p.42; https://home.treasury.gov/system/files/311/2022%20Federal%20Insurance%20Office%20Annual%20Report%20on%20the%20Insurance%20Industry%20%281%29.pdf

when the distribution of *a(x, p1, p2, …)* is used to find the expected value of a CAT bond or Insurance Loss Ratios, the result is consistent with observed data.

To be clear, we assume the Market-Implied distribution is a transformed version of the original distribution, using the function *a()*. We calibrate the parameters of *a()* such that when CAT bonds and insurance policies are priced using this transformed distribution, the prices are consistent with observed markets.

Proposed Risk Scaling Function Functional Form

In the management of losses by firms, a general three-tier risk financing strategy can be employed:

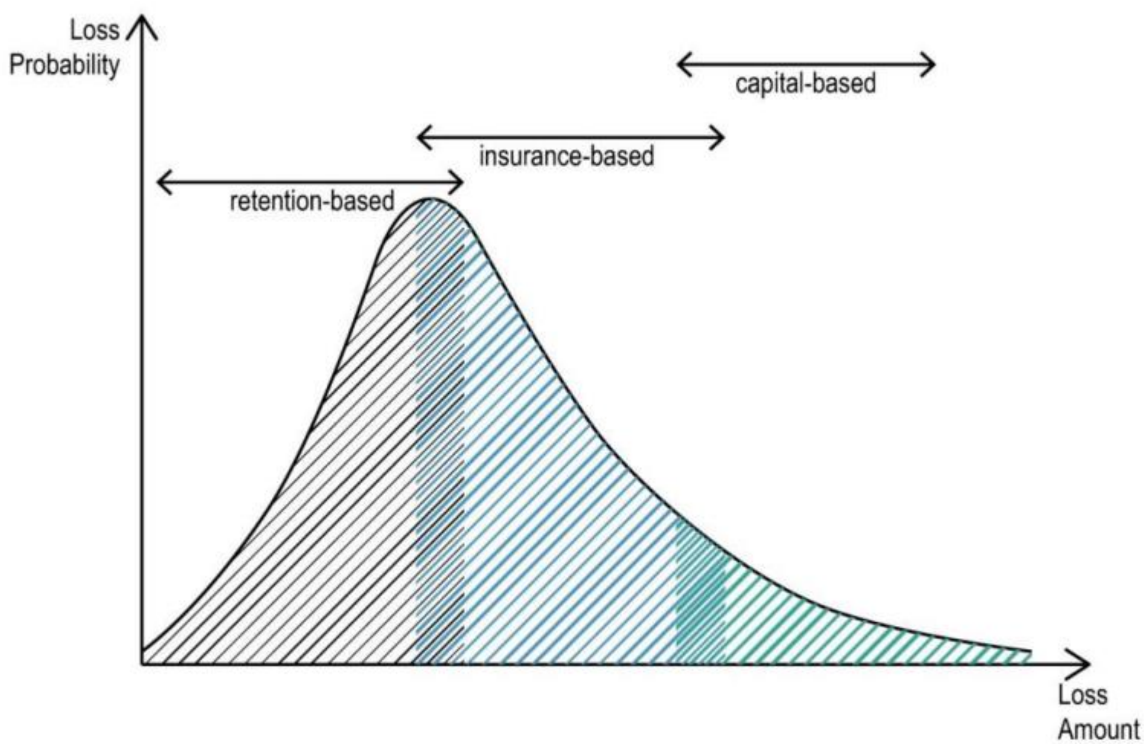


Figure 5 Three-tiered Risk Financing Strategy [10]

- *Retention-based tier:* For high frequency / lower-loss risks, firms often assume "deductible" amounts in insurance contracts, i.e., they will assume the losses under a certain amount.
- *Insurance-based tier:* For lower probability / higher magnitude risks (compared to the Retention-based tier), losses are transferred to insurance companies.
- *Capital-based tier:* Transfer tail / catastrophic risks (low probability / extreme loss) transfer to capital markets and reinsurers via CAT bonds and other products.

Corresponding to the three-tiered strategy, a three-segment Risk Scaling Function can be employed separately for the Financial Attribute. The Function is piece-wise linear, i.e., each segment is linear with

[10] Carolyn Kousky, Katherine Greig, and Brett Lingle, "Financing Third Party Wildfire Damages: Options for California's Electric Utilities", February 2019, Wharton Risk Management and Decision Processes Center

a slope determined from market or financing policies. Noting that the LADWP CAT bond Attachment level of $125 million was a tenth of PG&E's transaction in 2018, tiers can be developed for the illustrative example.

1. The first segment corresponds to the Retention-based tier. For the example, its assumed that this ranges from $0 to $1 million, approximately a tenth of common deductible amounts in PG&E's insurance policies - in the millions to tens of millions range. The first segment has the slope set to 1.0 indicating a preference to "in-house" the higher-frequency/lower-consequence losses.
2. The second segment represents the Insurance-based tier, and its range is from $1m to $100 million, with the upper bound corresponding to a tenth of the "Attachment" point for the AB 1054 Wildfire Insurance Fund's IOU coverage assumptions (beginning at $1.0 billion). Its slope, *slope 2*, will be found by calibration.
3. The third segment represents the Capital-based tier and its range is $100 million and above. Its slope, *slope 3*, will be found by calibration.

Technical Note 1 describes the calibration routine used to obtain the values of *slope 2* and *slope 3*. The calibrated parameters are summarized below. PG&E has also provided a spreadsheet that implements the calibration.

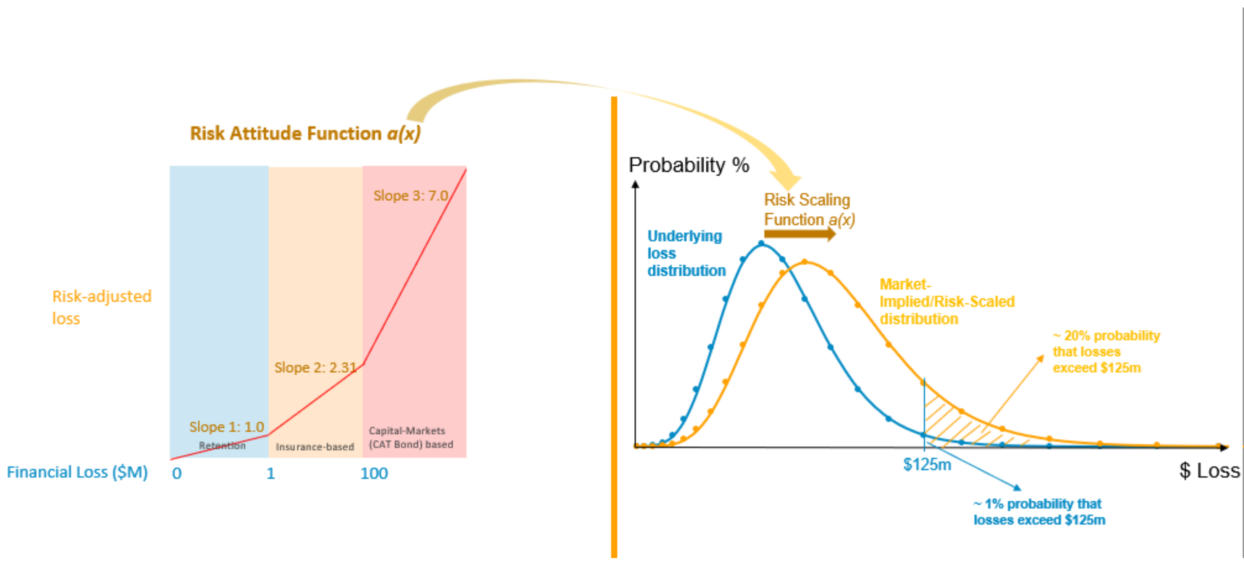


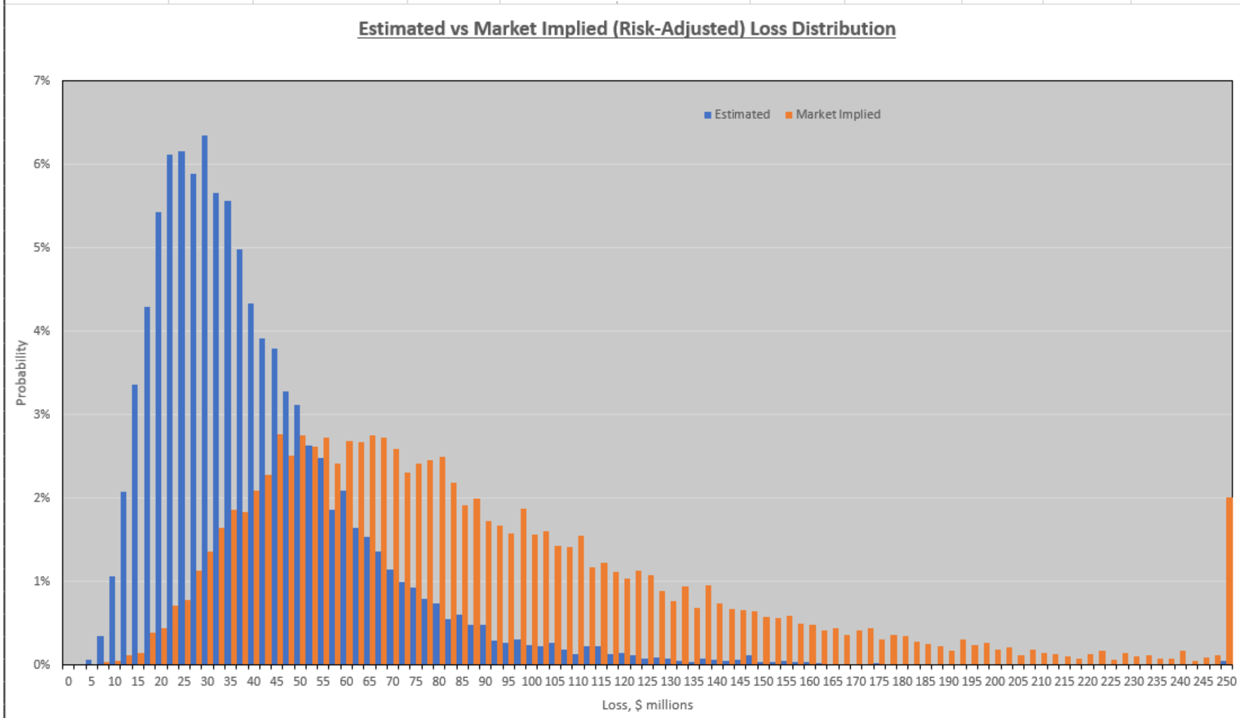
Figure 6 Calibrated Risk Scaling Function (Illustrative)

Illustrative Scaling Function Calibration

Annual Expected Loss	$ 42.0	million	
Attachment ($m/yr)	$ 125.0	Expected Loss/Event	$ 10.5
Coverage ($m/yr)	$ 30.0	Stdev/Event	$ 12.1
Num fires/year	4	Monte-Carlo Mode	**Static**
Num samples	10,000	Set as Static Value	

Scaling Function

	x		Slope	y
Breakpoint 1 ($m)	$ 1.0	s1	1.00	$ -
Breakpoint 2 ($m)	$ 100.0	s2	2.31	$ 1.0
Breakpoint 3 ($m)	> $100.0	s3	7.00	$ 229.2



Annual WF Loss Avg		Cat Bond Coupon			Insurance Losses			Probability of >$125m loss	
Underlying	Market Implied	Underlying	Market Implied	Multiplier	Underlying	Market Implied	Loss Ratio	Underlying	Market Implied
$ 42.18	$ 93.07	0.70%	15.03%	21	40.83	80.43	51%	1.11%	20.06%

Figure 7 Output from a Monte-Carlo Run of Calibration Spreadsheet

The Risk-Scaling Function and Market-Implied distribution obtained thus can be used to assess wildfire risks, mitigation benefits and provide other information. For example, the estimated Market-Implied annual Wildfire losses are approximately $93m, compared to the expected value of $42m. The probability of a loss of greater than $125m is approximately 20% compared to approximately 1% from the original distribution.

Incorporating ESJ Priorities

The parameters for the Risk Scaling Functions were calibrated on economic data (prices), which might not reflect ESJ priorities. However, as an option, the slope parameters in the Risk Scaling Functions can be further increased (e.g., by 10%) when mitigations in Disadvantaged and Vulnerable Communities (DVCs) are considered. This will lead to higher risk values, and in turn, higher benefits for mitigations in DVC areas, all other things being equal. The additional increases to the slopes can either be determined by the Commission, or perhaps based on existing data. For example, they could be tied (inversely) to income-levels in DVCs. Therefore, PG&E considers the Market-Based Approach to be flexible enough to incorporate changing societal values based on real-world events and concerns.

Non-Wildfire Risks

In the implementation example above, Wildfire Risk was addressed. However, a review of the Artemis Catastrophe Bond Deal Directory reveals CAT bonds exist for various other Risks as well (earthquakes, cyberattack, flood, etc.). Therefore, in an ideal situation, Risk-specific Risk-Scaling Functions could potentially be developed from relevant market information for each of the IOU's Risks. For now, PG&E will review and identify existing sources of information to see how they can apply to its Risks. For example, earthquake CAT bond and insurance policies might be used to develop the Risk-Scaling Function(s) for PG&E's Real Estate and Facilities Failure Risk. General liability insurance policies might be used to infer functions for other Risks. PG&E expects that as more experience is gained with employing the market-based approach in the RDF, participants will become more skilled in identifying relevant data to consider.

Conclusion

There is no need for the CPUC to mandate a specific Risk Scaling Function, and such an approach may indeed turn out to be counterproductive. For instance, assume that there is a mitigation program that provides the same risk protection as a financial instrument or insurance policy. With a mandated Risk Scaling Function such as a linear function with a slope of 1.0, the mitigation program will likely be valued *lower* than the financial product priced by competitive markets. A physical mitigation program is a superior product to financial risk transfer, and if the RDF is incapable of recognizing this, it is in peril of becoming irrelevant.

At its essence, the Risk Scaling Function is a powerful feature of the RDF to use in developing consistent and accurate assessments of Risk, such that policies and investment decisions can be made across various settings (insurance, asset management, etc). Using objective data, IOUs' risk-mitigation programs can be assessed against the market mechanism of risk transfer. Accordingly, IOUs should maintain the ability to apply the latest information and innovations from across industries to the Risk Scaling Function such that the RDF retains its relevance and vitality.

Answers to Planning Questions

1. In previous RAMP filings, did the IOUs apply a unique scaling function individually to the three attributes (i.e., Safety, Reliability, Financial) or did they apply the same scaling function to all three attributes equally? Depending on which approach was used, please provide the rationale for this approach.
   PG&E Response: As provided in Ch. 3 of PG&E's 2020 RAMP Filing, PG&E used a non-linear scaling function that captures aversion to extreme outcomes that complied to MAVF Principle 5. This non-linear scaling function was implemented to address Low Frequency High Consequence events, the 100 scaled unit cap, and to accurately quantify the experience gained from the Camp Fire.
2. Should IOUs maintain the flexibility to determine an appropriate Risk Scaling Function for their enterprise risks in the RAMP/GRC? If so, why? If not, why not?
   PG&E Response: Yes. PG&E further provides in this whitepaper what it believes is a reasonable approach that highlights how the flexibility can be used to achieve a consistent view of risk across industry.
3. What are the implications of adopting a specific Risk Scaling Function or policy towards such a Risk Scaling Function?
   PG&E Response: The implications of adopting any specific Risk Scaling Function would likely result in inconsistencies with how markets price risk, which could result in adverse impacts for society. For example, assume that there is a mitigation program that provides the same risk protection as a financial instrument or insurance policy. Adopting a specific Risk Scaling Function, like a linear Risk Scaling Function with a slope of 1.0, the mitigation program assessed with the RDF will likely be valued *lower* than the financial product priced by competitive markets. A physical mitigation program is a superior product to financial risk transfer, and if the RDF is incapable of recognizing this, it can have detrimental impacts on society and will be in peril of becoming irrelevant. On the other hand, the market-based approach is a proposed *policy* towards Risk Scaling Function(s) that results in consistent and complementary decision across industries and sectors because it explicitly seeks to align Risks assessed with the RDF with the markets and hence society's.
4. D.22-12-027 replaced the MAVF with the Cost-Benefit Approach. Does this shift to the Cost-Benefit Approach lead to any significant change in thinking or policy about the Risk Scaling Function?
   PG&E Response: Yes, as articulated above, the Cost-Benefit Approach shifted the conversation from a relative, artificially-derived unit to a grounded and intuitively understandable unit, the dollar. This benefit extends to allow the RDF to be comparable to independent dollar-based markets that also consider risk, e.g., the insurance and capital markets.
5. How is the prioritization of risk mitigations by the IOU affected by the use of a Risk Scaling Function?
   PG&E Response: With the Market-based Approach, decision-making, including the prioritization of risk mitigations will become consistent with, and complementary of policies and priorities in other risk-related sectors like insurance and capital markets.
6. Whose risk attitude should be represented by the Risk Scaling Function? Why?

PG&E Response: Risk Scaling Function(s) developed to be consistent with market prices would represent societal risk preferences (i.e., the cost that society places on the risk) because in general, market prices minimize costs to society.

7. Can Risk Scaling Functions incorporate ESJ concerns and priorities? If so, how? Should Risk Scaling Functions incorporate ESJ concerns and priorities? If so, why?
   PG&E Response: Yes, the Market-based Approach can include additional parameters (e.g. multipliers) to be used by the Commission to explicitly incorporate ESJ priorities in the Risk Scaling Function.
8. What considerations should be accounted for in the development of Risk Scaling Functions?
   PG&E Response: Please see the section "Considerations and Principles" above.
9. Are there any general principles that can be adopted to guide the development of Risk Scaling Functions?
   PG&E Response: Please see the section "Considerations and Principles" above.
10. Can a linear Risk Scaling Function ensure that low probability, high consequence risk events are properly valued within the Cost-Benefit Approach? If it can, how? If it cannot, why not?
    PG&E Response: Low probability, high consequence risk events are more uncertain (how does one assess that an event is 1-in-100,000 or 1-in-1,000,000 when the event has not occurred before?) than high probability, low consequence events. A linear Risk Scaling Function does not consider the higher uncertainty for low probability, high consequence risk events. PG&E believes that the more productive approach is to ask "what is the risk-adjusted probability one estimate that the high consequence event would occur, reflecting one's attitude toward high consequence risk?" Is this probability estimate reasonable? What do others think? In particular, what do the Insurance and Capital Markets consider to be the probability of the high consequence event used in expected value calculations given uncertainty? By this line of reasoning, one is able to construct the probabilities that reflect the market participants' view, and one might discover that the risk-adjusted probability is higher than what was originally estimated. This approach is described in the main text.

Technical Note 1

LADWP's LA DWP Power Protective Re Ltd (series 2021-1) and Insurance Loss Ratios were presented in the implementation example in the main text. This note describes how a model can be built to calibrate the slopes of the three-segment Risk Scaling Function proposed to transaction prices for these two risk-transfer instruments. The model is implemented using Monte-Carlo simulation in the spreadsheet accompanying this paper.

Risk Scaling Function Considerations

One way to view how the Risk Scaling Function captures risk preferences is as a function that modifies the original probability distribution of the risk event in some manner such that the expected value of the resulting modified distribution determines how much to pay for eliminating the risk. In the case of the LADWP CAT bond, since the transacted price was reported to be over the expected value, it implies that the function should take the original distribution and add more weight to the tails, thereby adding a risk *premium* of approximately 20-23 times the expected value, as reported.

Let W be a random variable representing the consequences, in dollars, of a wildfire event *i*. Therefore

$$P(W_i \leq w) = F_w(w, \propto)$$

hence F_w is a cumulative distribution function (cdf) of W_i and α is a list (tuple) of distribution parameters[11]. Let $a_k()$ be a risk-scaling function, then

$$P(W_i^* \leq w) = P(a_k(W_i) \leq w) = F^*(w)$$

where $a_k()$ is parameterized by tuple k, i.e. W_i^* is itself a random variable with a cumulative distribution F^* derived from $a_k()$ and $F_w(\propto)$[12]. Herein F^* (and accompanying density function f^*) is termed the *risk-adjusted* probability measure[13], whereas F_w (and accompanying f_w) is the underlying or physical probability measure.

Calibrating the Risk Scaling Function to the CAT Bond and Insurance Data

The calibration approach here attempts to infer, under certain assumptions below, the *implied* risk-scaling function $a_k()$ leading to the risk-adjusted measure that would result in

1. a 15% coupon (i.e., 15% of $30 million = $4.5 million price) for the LADWP CAT Bond, and
2. an Insurance Loss Ratio in the 50% - 75% range.

One should note that the losses related to the Insurance and Capital Markets are often *annual* cumulative losses, whereas in the RDF, W_i and W_i^* are random variables representing individual events, which must therefore be summed over a year to obtain the annual loss random variable/distribution.

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[11] E.g., if F_w is a Normal distribution then $\alpha = (\mu, \sigma)$

[12] Papoulis, Athanasios, Probability, Random Variables, and Stochastic Processes, Third Edition, 1991, Ch 5, pp.86-93.

[13] In financial applications (e.g. Black-Scholes option pricing, etc.), *F*/f** is commonly referred to as the risk-neutral measure, because it is the (adjusted) probability measure that would make investors behave in a risk-neutral manner (ie, price securities/options with a linear utility function, or purely based on the expected value) (see Hull - Options, Futures, and Other Derivative Securities, Second Edition, 1993, pp.221-223, and Risk-neutral measure - Wikipedia). However, in this setting this terminology is replaced with "*risk-adjusted"* to minimize confusion.

This leads to the definitions of the annual cumulative underlying losses and the annual cumulative risk-adjusted losses

$$W_{\Sigma} = \sum_{i \epsilon [n]} W_i$$

$$W_{\Sigma}^{*} = \sum_{i \in [n]} W_i^{*}$$

where n represents the number of such events per year. For the implementation example, *n=4* is assumed, although this assumption can be changed in the spreadsheet to take values between 1 to 10.

Making the adjustments and considerations above, and with no loss of generality, the CAT bond can be modeled as a financial option structure known as a call spread (i.e., simultaneously purchase a call option with predetermined strike price and sell another call option with a higher strike price) which has a payoff diagram shown below:

Payoff = max(Loss – Attachment, 0) – max(Loss – (Attachment + Coverage), 0)

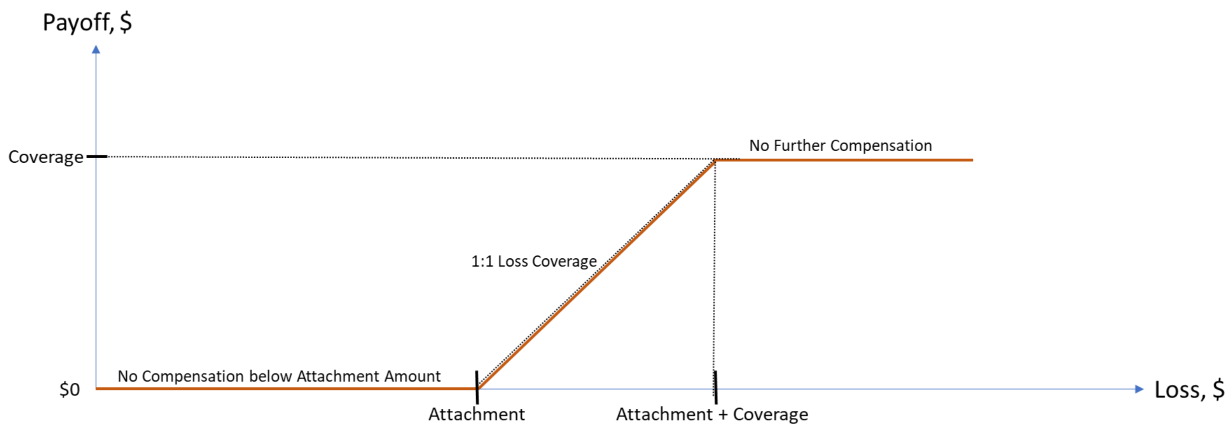

Figure 8 Simplified Financial Payoff of a CAT Bond

The coupon of the CAT bond, C_b^*, would be the discounted (at rate *r*), expected value under the risk-adjusted *probability measure* of the call spread with lower strike at the Attachment level A_b, and higher strike at $A_b + K_b$ where K_b is the Coverage amount, expressed as a percentage of the Coverage (or principal), ie

$$C_b^* = \frac{e^{-rt} E[max(W_{\Sigma}^* - A_b) - max(W_{\Sigma}^* - (A_b + K_b))]}{K_b}$$

Likewise, the underlying coupon, C_b, is the expected value under the underlying distribution,

$$C_b = \frac{e^{-rt} E[max(W_{\Sigma} - A_b) - max(W_{\Sigma} - (A_b + K_b))]}{K_b}$$

The risk premium multiplier, M_b, is the ratio of the market coupon to the underlying coupon.

$$M_b = \frac{C_b^*}{C_b}$$

While there isn't a definite financial payout structure for insurance policies[14] as there is for a CAT bond, as an estimate, insurance coverage can also be modeled as a call spread consisting of a long call option strike with strike price given by the Deductible amount, and a short position in another call option with strike given by the sum of the Insurance Coverage and the Deductible (thereby capping the coverage). This is illustrated below.

Payoff = max(Loss – Deductible, 0) – max(Loss – (Insurance Coverage + Deductible)), 0)

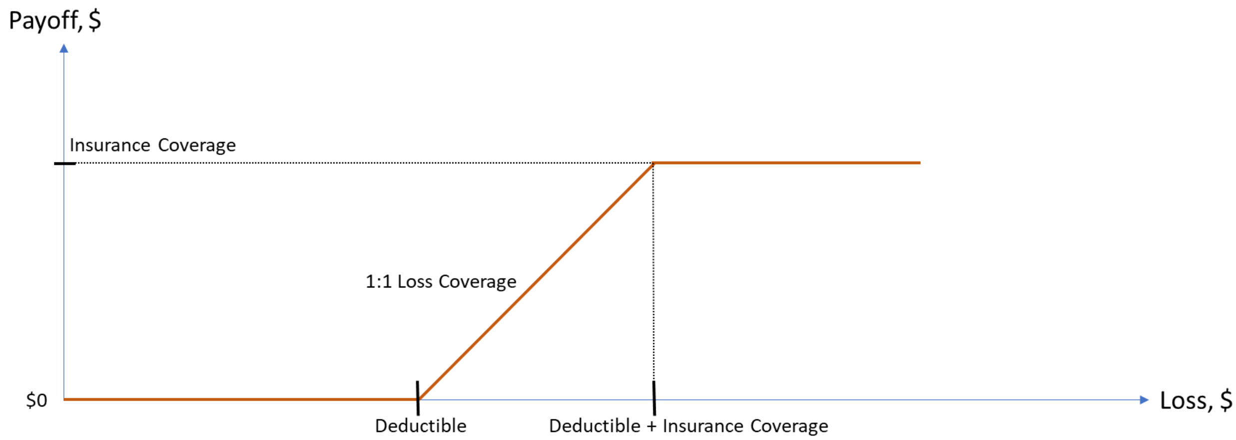

Figure 9 Simplified Payoff of Insurance Policies

The insurance premium, *I**, would be the discounted, expected value of the call spread under the risk-adjusted *probability measure*, given the Deductible amount *D* and the Coverage amount K_i, ie

$$I^* = e^{-rt}E[max(W_\Sigma^* - D) - max(W_\Sigma^* - (D + K_i))]$$

Modeled insurance payouts under the underlying distribution, *I*, is likewise defined as

$$I = e^{-rt}E[max(W_\Sigma - D) - max(W_\Sigma - (D + K_i))]$$

Hence the Insurance Loss Ratio, R_I, is

$$R_I = \frac{I^*}{I}$$

[14] For example, a bespoke insurance "tower" of coverage can be obtained.

The market prices and information on the underlying distribution provided by LADWP form a set of constraints that together determine the risk-adjusted probability measure These are listed below:

Underlying Distribution Mean:

$$E[W_\Sigma] = \$42\ milion/year \quad (1)$$

CAT bond transacted Coupon:

$$C_b^* = 15\% \quad (2)$$

Modeled/Underlying CAT bond Coupon:

$$0.64\% \leq C_b \leq 0.76\% \quad (3)$$

Risk premium Multiplier:

$$20 \leq M_b \leq 23 \quad (4)$$

Insurance Loss Ratio:

$$50\% \leq R_I \leq 75\% \quad (5)$$

The steps required to determine the implied risk-scaling function $a_k()$ are

1. Developing historical individual event loss (consequences, in $) distributions, i.e., developing the distribution of W_i based on historical data such that equation (1) is satisfied.
2. Selecting a functional form (and parameter set k) for risk-scaling function $a_k()$ that transforms the underlying distribution to the *risk-adjusted* distribution, W_i^*.
3. Determining the annual loss distribution for the sum of the individual *risk-adjusted* event distributions; i.e. determine $W_\Sigma^* = \sum_{i\in[n]} W_i^* = \sum_{i\in[n]} a_k(W_i)$.
4. Find the values for parameter set k such that Equations (2) through (6) above are (approximately) satisfied.

Each step is discussed in detail below.

Step 1. Developing Historical Individual Event Loss Distributions

The objective of the calibration is to find the Risk Scaling Function that transforms the underlying probability to the market-implied probability measure. Therefore, it is necessary to develop the underlying probability measure as a starting point.

For the purposes of modeling LADWP wildfire risk, the per event consequence distribution, *Wi*, for the financial Attribute is assumed to be lognormally distributed. LA DWP stated that consultants hired by the department estimated wildfires to cost approximately $42 million per year[15]. The standard deviation of the per-event consequences will be calibrated based on LADWP's modeled Coupon rate, ie

$$W_i \sim \text{Lognormal}\left(\frac{\$42\ \text{million}}{n}, \bar{\sigma}\right)$$

[15] https://controller.lacity.gov/audits/dwps-wildfire-prevention

Find $\bar{\sigma}$ such that equation (2) above is satisfied. This was accomplished with the Monte-Carlo based spreadsheet, assuming values for $\bar{\sigma}$ by trial and error until equation (1) was satisfied (see spreadsheet cell B44 – Annual WF Loss Avg, Underlying). The standard deviation was found to be $12.1 million.

Step 2. Selecting a Functional Form for Risk Attitude Function $a_k()$

Consistent with the documentation in the main text, $a_k()$, applied to the per-event loss, consists of three piecewise linear segments.

$$a_k(w) = \begin{cases} w, \quad w < b_1 = \$1.0m \\ s_2(w - b_1) + b_1, \quad b_1 \le w < b_2 = \$100.0m \\ s_3(w - b_2) + s_2(b_2 - b_1) + b_1 \quad w \ge b_2 \end{cases} \tag{6}$$

Step 3. Determining the Annual Loss Distributions

For each Monte-Carlo sample of the *Wi* 's, equation (6) was applied to arrive at the risk-adjusted distribution, W_i^*. This is performed in Column X to AG of the spreadsheet. The average of the samples (i.e., the Market Implied average annual loss) is reported in Cell C5.

Step 4. Finding s_2, s_3

Finally, a trial-and-error method was used to determine the values of s_2 and s_3 so that equations (2) through (5) are approximately satisfied. The table below documents where to find the relevant results and parameters in the spreadsheet.

Item	Spreadsheet Location.	Comments
Underlying Annual Wildfire Loss	Cell B44	Subject to Equation (1), achieved by varying cell D5 (lognormal standard deviation)
Transacted Coupon	Cell E44	Subject to Equation (2)
Modeled Underlying Coupon	Cell D44	Subject to Equation (3)
Risk Premium Multiplier	Cell F44	Subject to Equation (4)
Insurance Loss Ratio	Cell I44	Subject to Equation (5)
Risk Scaling Function segment 2 slope, s_2	Cell I4 (slope2)	Vary to solve Equations (2) through (5)
Risk Scaling Function segment 3 slope, s_3	Cell I5 (slope3)	Vary to solve Equations (2) through (5)