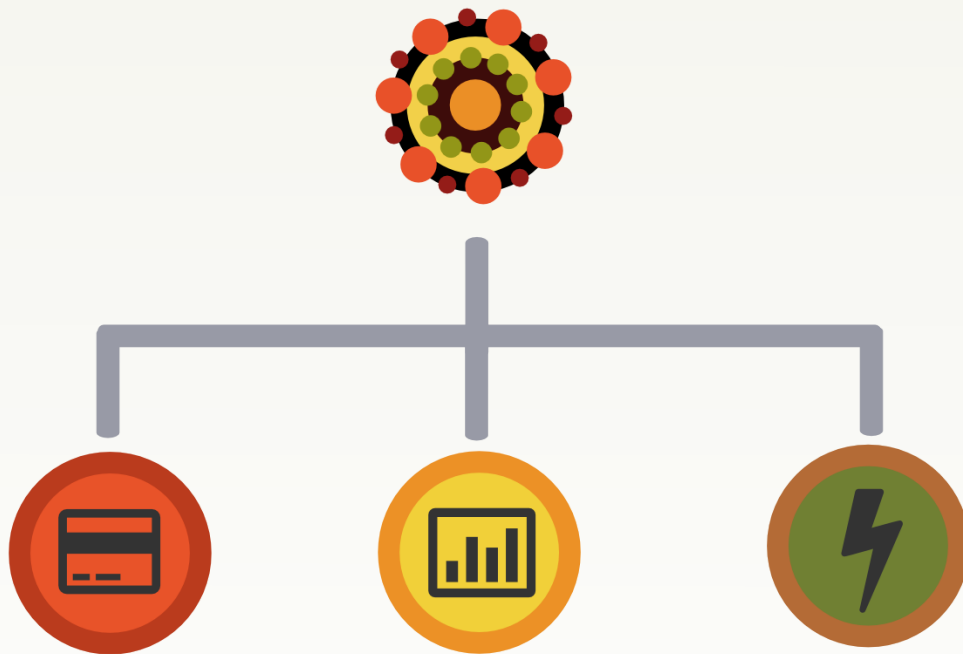


# OPENRISK WHITE PAPER

## Open Risk Taxonomy

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The open future of risk management

## SUMMARY

We develop a taxonomy for risk models that aims to support an open source risk models framework. The proposal builds on and extends some commonly used risk taxonomies within financial services firms but introduces some significant new elements.

We first review the motivation for risk taxonomies, the concepts and tools that are involved and some of the weaknesses of current schemes. We try also to clarify the link between risk models and risk taxonomies.

The white paper has three main sections:

- A *Review* section discussing the motivation, concepts and precedents around risk taxonomies
- The *Risk Model Taxonomy* section documenting the current version of the taxonomy

For easy exploration we illustrate the concept with an [online implementation](#) of a taxonomy explorer.

## Further Resources

The [Open Risk Forum](#) is a meeting place for risk managers and the primary venue for discussing open source risk model development. The [Open Risk Academy](#) offers a range of online courses around risk management, which utilize the latest in interactive eLearning tools. Please inquire at [info@openrisk.eu](mailto:info@openrisk.eu) about course schedules.

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# Review

## Motivation

In a related white paper<sup>[1]</sup> we developed a proposal for an open source application programming interface (API) that allows for the distributed development, deployment and use of financial risk models. The API aims to offer an answer to the following key question: how to integrate in a robust and trustworthy manner diverse risk modeling and risk data resources, contributed by multiple authors, using different technologies, and which very likely will evolve over time.

While open source risk models conforming to the API could be developed in any ad-hoc manner, a *risk model taxonomy*, namely a framework for classifying the variety of risk models according to their defining characteristics is an essential organizational tool to help manage a diverse code base. Amongst others it will facilitate coherent grouping of models according to their context of use, which in turn helps specify meaningful quality standards for model acceptance.

This white paper focuses precisely on developing a consistent and easy to use taxonomy that will support further risk model development work.

While our focus is on quantitative risk *models*, the subject is closely related to the more general *risk taxonomies*. Hence we review and incorporate important elements from current risk taxonomy usage, in particular as already reflected in financial regulation. In turn this *public* taxonomy maybe also a useful benchmark for internally developed taxonomy schemes.

The currently released version is the initial release. We expect the taxonomy to evolve as the open source risk modeling framework develops further and with feedback from users.

## The Need for a Taxonomy

Risk is commonly defined as the adverse impact due to uncertainty (unpredictability of future course of events) on objectives. The impact is very commonly measured in monetary terms even though it is not always possible to link the realization of a negative turn of events to a precise amount of economic loss.

The risk taxonomy enters in risk management activity as a tool to help primarily with the following two tasks:

1. Establish a degree of *completeness* in the coverage of risks
2. Identify potential *linkages* between risks factors

The second objective exemplifies what is sometimes denoted as a "holistic" approach to risk management. The mandate to create such an integrated view of risks resides typically with Enterprise (Wide) Risk Management or Integrated Risk Management teams.

While some general patterns are evident, there is currently little formalization of what is an adequate internal risk type taxonomy (and the corresponding risk model taxonomy), especially away from the regulatory mandated operational risk taxonomies[2].

**Box 1. A Risk Taxonomy is an Essential Component of Sound Risk Management**

- Principle 2: Banks should develop, implement and maintain a operational risk management framework (ORMF) that is fully integrated into the banks overall risk management processes. The framework for operational risk management chosen by an individual bank will depend on a range of factors, including its nature, size, complexity and risk profile
- The establishment of an ORMF includes the establishment of a common *taxonomy* of operational risk terms which should include definitions of operational risk and operational risk event types

The quality of the risk taxonomy can have wide ranging impact. As was put eloquently in[3], “The presumption that the event taxonomy is correct is central to the modeling process”. The “modeling” being refer to in this case concerns capital requirements for operational risk. The degree to which *risk sensitive* as opposed to *risk agnostic* views are adopted for managing bank capital[4], it is ultimately contingent on risk management fulfilling the stated ambition of holistic approach that captures all elements of risk.

A key challenge for a verifiable risk taxonomy is that we only have a sketchy description of *what* is at risk. Our ability to identify and manage risk is strongly linked with a well articulated catalog of the firm’s objectives[5] yet like many other business sectors, financial services are largely an agglomeration of historical business practices, approximate accounting and empirical risk management rather than a coherent and articulated operating model. Hence “what” is at risk (which objectives, underpinned by what business process etc.) is many times discovered ex-post, once a vulnerability is revealed in a crisis. It will be instructive for the sequel to briefly discuss a number of different points of view one could adopt as a thought framework for identifying and measuring risks. Amongst a range of possibilities we would mention at least:

## The regulatory taxonomy

On the face of the above challenges to derive an intrinsic assessment of risks, regulation has adopted an approach that has essentially evolved *in response to crises*. Each financial system crisis in the modern era identified a new set of vulnerabilities (interest rate risks, market risks, credit risks, liquidity risks, conduct risks etc) and regulation has been introduced as a mitigation tool to prevent a repetition of a similar risk realization.

As a consequence of previously formalized interventions, any risk manager working currently within the financial sector is aware of the standard, regulatory driven, “risk taxonomy” comprised of market, credit and operational risks. It is not atypical that the entire formal risk function is organized along exactly those three lines (the infamous Risk silos). These categories reflect and focus essentially on the regulatory *minimum capital requirements* as those have developed over the previous two decades [6].

Alas the regulatory categories do not form an intrinsic representation of the firm risk profile but consist only of the to-date (historically observed) “tip of the iceberg” of risk factors. The multi-billions worth

of losses in recent examples of new *liquidity and conduct* risks illustrate beyond doubt the danger of staying on the surface of things. While we may surmise that by now we may have indeed covered empirically all forms of financial risk management failure, this is not necessarily true: Rapid technological developments suggest that the next financial crisis will likely engulf a different species (or business line) of financial institution and likely for *different reasons* than any previous crisis.

Indicative of the challenge involved in developing an effective risk taxonomy is the need to resort to an enumerative style for the different types of risk, without adequately addressing the logical relationships and interconnections between risks. It is best to illustrate the problem with some concrete examples of this phenomenon:

#### **Box 1. Pathologies of Enterprise Risk Management taxonomies**

- Mixing business line taxonomies with risk taxonomies: It is very frequent to make a distinction between "credit risk" and "counterparty risk". In both instances the actual risk is that of an obligor defaulting and arguably this is the main risk element. Yet the use of different terminology is persistent across the industry and comes for differences in business lines (lending business versus traded markets) and different product focus (loans versus OTC derivatives). Yet this approach is not without negative consequences: E.g., for purposes of credit risk aggregation it is the *total* credit exposure to an obligor that matters, irrespective of which business line or which product is involved.
- Mixing elementary risks with aggregation risks: E.g., Credit concentration risk is frequently mentioned as a distinct risk type, whereas it is clearly not. Concentration cannot manifest separately from a portfolio, that is, an *aggregation* of credit risks. Its treatment as a separate risk category suggests a taxonomy framework where the concept of individual (elementary) risks and intra-risk aggregation are not fully internalized. The implication might be that the management of portfolio wide risks might be following regulatory prescriptions rather than being fully embedded in the business.
- Confusing accounting taxonomies with risk taxonomies: The confusion between "market risk" vs interest risk in the "banking book". Here we have an example where accounting practices (accrual / banking book) obscure the nature of the risk (which is linked to the development of interest rate markets) and possibly hinders the proper aggregation of rates risk across the trading and banking book.

Another weakness of regulatory risk taxonomies is the relative lack of attention to non-capitalized risks. Besides credit and market risk, the regulatory decision in Basel II was to isolate for quantification and capitalization purposes a specific set of business risks (*operational risks*) that were deemed as potentially having material impact on the ability of the firm to maintain operations.

While business risks *not* falling under that operational risk category do receive significant attention internally (in terms of strategy, planning etc.) the relative dearth of literature in this area from a risk management point of view [7, 8] suggests that it is not characterized by a high degree of development or integration with the rest of risk management.

## Conceptual frameworks behind risk taxonomies

With the motivation provided in the previous section we proceed to explore what analytic frameworks could be used as a basis for a good risk taxonomy.

### The bricks and mortar view

*"The firm as a collection of glass buildings, people, and wired computers"*

This view is certainly relevant for understanding the *physical risks* facing the organization (natural disasters, health epidemics, equipment malfunction etc). A taxonomy of such risks would naturally link to the physical inventory of what constitutes the firm. Furthermore, since natural phenomena are generally governed by *stable* physical laws, estimating statistical risk models for this category of risk would appear a tractable undertaking.

Yet it is clear that the majority of a financial firm's objectives and corresponding risks are *not* accurately captured by its physical footprint. A major bank can go bankrupt with little tangible evidence beyond a few employees exiting from the front door holding cartons of personal belongings. It is thus necessary to consider how to describe the essence of the firm from an *information* point of view as well as the physical perspective.

### Information based views

#### The financial (accounting) view

*"The firm as a balance sheet of assets and liabilities".*

In this abstraction the aim is to project every important aspect of the firm onto a one dimensional universe of monetary values, which can be positive or negative. Aspects with positive value are labeled assets, negatively mapped elements are labeled liabilities. The sum total is the firm equity, the net value accruing to the owners of the firm.

The financial view is currently the most detailed effort to provide a verified, even if stylized, "state" of the firm in the sense of describing "what" constitutes the firm at any given moment. While published balance sheets are only summaries, the real balance sheet is an electronic ledger which more or less reflects *every* material contribution of "monetary value" to the firm.

While monetary value is obviously quite important for a financial firm, it is not necessarily a sufficient metric for capturing all the relevant information required for describing the firm state at a given moment. The main reason is that only a very small subset of the firm's reality is accurately captured by a single piece of data such as monetary value (a cash balance comes to mind). There are two key problems with the accounting view:

- Normally a significant part of firm substance (and value) is in so called "franchise value", a diffuse collection of "intangible assets" which define what the firm stands for and is capable of in terms of setting and delivering business objectives.
- Even for well documented aspects of the firm, e.g. where legal contracts define exactly that is the asset or liability, there can be significant difficulty to map contracts into a value. Contractual complexity, contingency on future events, lack of suitable reference points in the market etc. means that the mapping of a complex situation into a number is at best approximate.

- Further, what is being recorded as value is, broadly speaking, an *expectation*. The balance sheet stores no information about how the value of contracts behaves in the different possible future states and the same expectation may derive from very different distributions of future returns.

Hence the balance sheet view, while useful as a *check list* of what should be minimally in scope of risk management does not offer itself sufficient information for reconstructing the risk profile of the firm.

### **The legal (contractual) view**

*"The firm as a collection of contracts".*

The legal or contractual view is a more accurate view of the financial firm. It comprises of the list of precise agreements (contracts), responsibilities, options, payment obligations etc. of all relevant agents. We can think of all these contracts as a *documentation ledger* or database, which can help us identify all legal entities that interact with the firm, and what financial exchanges are to be expected with them in all future states of the world.

This documentation ledger includes for example, the work contracts of management and employees, which play a significant role in aligning incentives between them and the firm (as legal entity). E.g., a fixed salary contract may have exactly the same current value as a stock option, but will give the holder of the contract very different incentives to try to shape the future states of the firm. In turn this has huge ramifications for risk management, because risk is precisely concerned with the set of adverse future states.

A legal documentation database approach to risk management is at present only a theoretical possibility. There is in most firms nothing like a comprehensive and *machine readable* "contracts" database on which to base a practical risk management framework. Indeed it is not unusual for risk practitioners to aim to leverage product documentation stored in accounting systems to reconstruct a useful set of contractual information.

Further, significant aspects of the firm are not strictly contractual but based on implicit understandings and/or conventions. Employees may perform above their "contractual obligations" if they associate with the values of the firm. Clients may expect that certain product clauses will not be enforced even though they are included in the documentation and the firm may choose not to enforce for reputation reasons. Indeed the financial firm must look beyond its direct relationships (employees, shareholders, regulators, clients, other market participants) to the society at large. The broader society is also operating by implicit contracts and/or beliefs, for example applying trust to substitute for lack of information and/or formal contractual relations. Any suggestion that this domain is too "soft" to be of practical importance for risk management is quickly dispelled by the tremendous destruction of franchise value that has followed the financial crisis: Loss of clients, employees, hardening stance of regulators, a hostile public etc., all attest to the very real risks embedded in non-contractual relationships.

Given the importance of non-contractual relations it would be advisable that risk managers develop also conceptual risk framework for managing this domain. We might speculate that the main tool for this purpose would be managing the *provision of information* (transparency) with various stakeholders.

### **The information processor view**

*"A firm as a set of information flows driving business processes"*

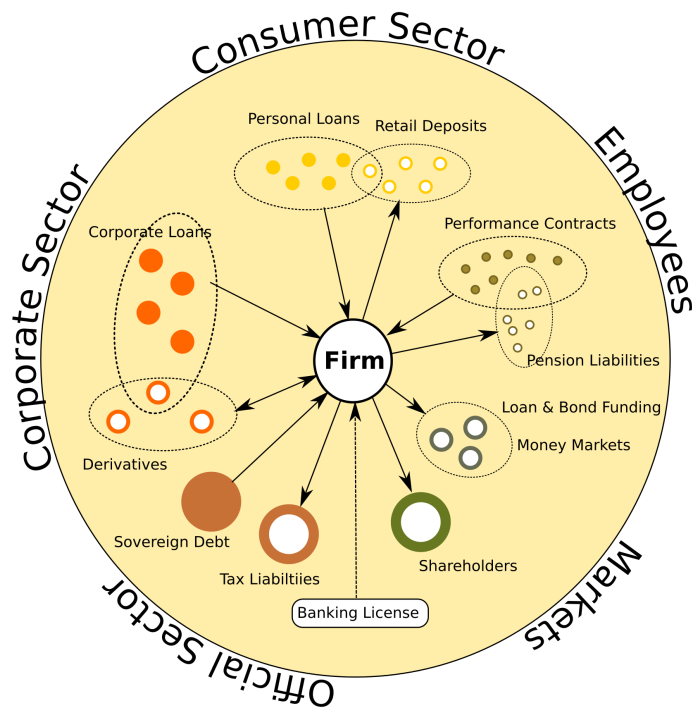


Figure 1: The firm as a collection of contracts. At any given moment there are contractual relationships with clients, employees, market participants etc. Clients can be different types of legal entities, from physical persons to sovereigns. Contracts can be for example credit agreements, deposit accounts, derivative contracts etc. The relationship with the official (government) sector is particularly important as it includes the license to operate, tax liabilities and typically also a significant store of value in the form of sovereign bond investments. Employees have individual or collective work contracts and in some jurisdictions also guaranteed pension entitlements. Finally, shareholders hold another set of crucial contracts, namely voting shares. Many contracts are either assets or liabilities - indicated by the direction of the arrow (towards the firm for assets, away for liabilities). Some contracts, e.g. derivatives or tax agreements can be assets or liabilities depending on states of the world. In the contractual view of the firm risks are linked to performance and enforceability of contracts. For example market risk is linked to value uncertainty of financial positions, credit risk is renegeing on contracts, liquidity risk can arise from options embedded in products etc.



We now discuss the most comprehensive but also the least developed view of the financial firm, namely the firm as a processor of information. It is a truism that information advantages are core part of the financial services competencies but there is little in terms of widely implemented frameworks for describing this landscape at a practical level of detail. What would such a framework look like?

One way to think about this is as a dynamic extension of the static contractual view. Contracts are only entered into and maintained as the result of information gathering and other supporting business processes. Internal and external data flows are critical for evaluating contract proposals and deciding about whether to enter into new ones. For example decisions on extending new lending are based on information collection that happens at both the client, portfolio and macro-economic level. These business processes might have an algorithmic component but are by and large in the hands of the management and employees of the firm. While *current* information is obviously of high importance, it is frequently only interpretable in the context provided by *historical data*. Hence the informational view of the financial firm is a collection of information processing algorithms (business processes) that crystallize decisions into contracts.

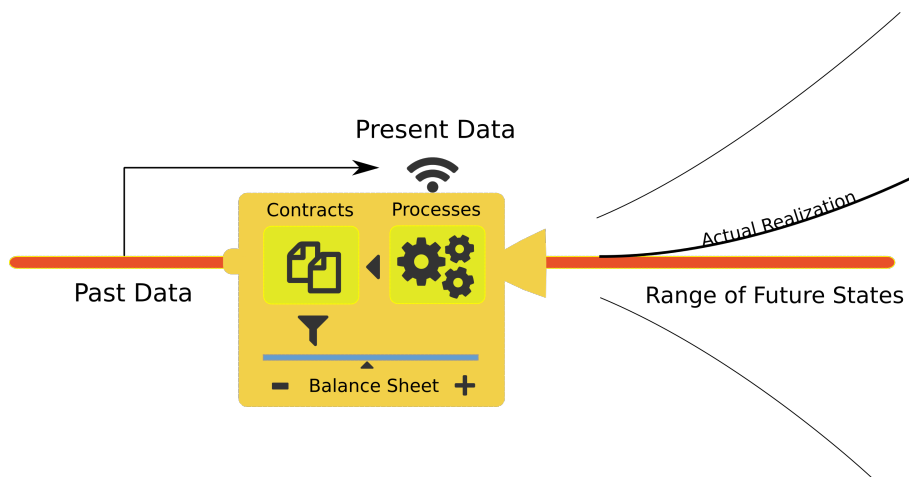


Figure 2: The financial firm as an information processing engine. Present and past data are analyzed for clues about the likely future developments by internal business processes. Once a concept for the likely future states is formed, new contracts are added to the existing set and modify the internal state of the firm. This is projected (in summary form) onto the balance sheet. As time proceeds new contracts replace in part older ones and the actual realization of external factors modifies the outlook for the firm. While this description of the firm is harder to translate into a "database", it makes it clear that there are significant risks associated with business processes and those precede and are less rigorously defined than risks related to existing contracts.

# Open Risk Models Taxonomy

As stated, our taxonomy ultimately aims to classify *risk models* rather than *risks*. The logical relationship between identified risks and the subset of risk quantification models is determined by the precise definition of a *risk model*.

The subset of *quantifiable risks* versus "hard to quantify" risks is primarily determined by whether we choose to include in our target the class of *expert based* models, that is models where the primary input towards a quantified assessment is the subjective opinion of one or more subject matter experts.

Our approach is (for the purposes of this taxonomy) to include expert based risk models, reflecting the de-factor reliance on subjective views in many areas of risk management.

We hence define as **risk model** any structured and documented procedure of deriving a risk measure.<sup>1</sup>

Risk models can be classified according to at least the following dimensions, proceeding from the more intrinsic features of a given risk and its quantification to the context of its use.

- By the *risk type* being quantified (the nature of the loss or threat)
- Whether quantifying an *elementary* risk type (e.g., the probability of an IT system failure) or an *aggregated* (composite) risk (e.g., portfolio credit risk)
- By the intrinsic *timescale* of the risk modeled (from seconds / intra-day market risks to decades for the credit risk in project finance or sovereign liabilities)
- Whether it quantifies discrete (lumpy) or continuous realizations (operational risks versus market risks)
- By the *model type*, e.g. statistical - based on historical data, theoretical (structural) making assumptions of "rational behavior", expert based, implied from market data etc
- By the *calibration approach* (to historical data, market data or expert opinion)
- By the *business line* using the model (e.g. retail, commercial or investment banking)
- Within each business line further by a *client / product matrix*
- By the *model use* (for risk acceptance, risk limits, hedging, accounting, regulatory reporting, pricing etc)

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<sup>1</sup>By this definition a simple guess does not constitute a risk model but an educated guess of a suitably organized expert panel, documented by a set of observables that are considered as informative along with e.g., their relative contribution in arriving to a decision *does* constitute a risk model

- By the *modality of usage* (informative, binding, automated or manual etc.)
- Finally, for business process risks, by whether we quantify inherent risk (before risk mitigation actions) or residual (after risk mitigation)

Our approach will focus on classifying risk types, decomposing each risk type category into a hierarchy of risks which capture the threats to the most important activities of a given business line. We obtain this classification tree with the following reasoning:

A monoline business operates by entering into a set of contracts and creating financial positions (portfolios) that persist over time. At the highest level we ask whether the risk we aim to quantify is linked to these contracts or to the business process itself. The contractually based risk category includes the classic financial (market and credit) and also insurance risks. Less commonly discussed in this group are issues such as employee work and pension contracts. The remaining non-contractual risks are threats to business processes such as generating new business, executing the business plan etc.

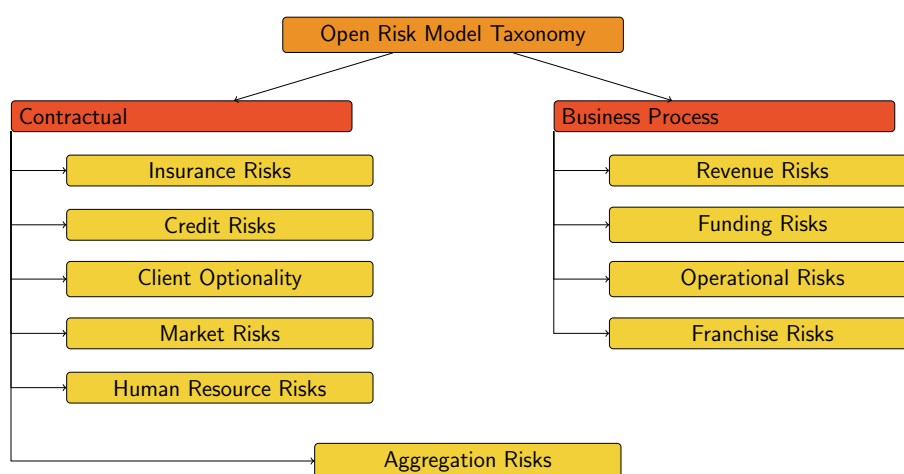


Figure 3: A risk taxonomy that is primarily based on the distinction between contractual and business process risks

## Business Process Risks

The Business Process Risks category contains all non-contractual risks that threaten the firm’s business plan objectives. In the absence of definitive legal descriptions, business process risks tend to be less well defined, but at high level we can differentiate them as follows:

### Revenue Risk

Revenue risk covers all risks pertaining to the ability to persist or grow profitable business operations. This means achieving sales targets (volumes), maintaining margins, containing production costs, making the right strategic investments etc. Conceptually it is useful to distinguish between risks affecting a *stable business plan* versus risks associated with *strategy changes*.

A list of contributing elements to new business risk is the following:

- **Market Share:** The risk that product volumes (as relative market share) will deviate from business plan or budget, leading to unexpectedly lower revenues
- **Market Size:** The risk of reduction in the wider market demand for the firm's product and services as a result of factors external to the firm or its competitors
- **Margin Risk:** The risk of lower profitability versus the business plan, as the result of tighter pricing (does not include funding cost component)
- **Costs Uncertainty:** The risk of lower profitability versus the business plan as the result of higher origination costs due to external or internal factors
- **Strategy Risk:** The risk that forward looking projects that modify the firm's business plan fail to deliver the expected return versus investment

In terms of quantifying revenue risks volumes, margins, costs, individual productivity etc are all observable variables that develop largely continuously. They can be analyzed in connection with other factors. Strategy modifications may create more lumpy changes and would in general be more difficult to quantify their risk profile.

## **Funding Risk**

The funding risk category covers risks linked to uncertainty around the availability of future external funds for financing operations. In most current structures financial firms are generally in need to refinance on an ongoing basis, but existing counterparties have no contractual obligation to roll funds and certainly not at the same rate. The availability and required rates of new depositors is also uncertain.

While one might be tempted to treat funding risks alongside market risks (e.g., as a form of rate risk) there are some substantial differences: the funding rates concern the firm itself and are not traded in an independent market while the available volumes are also a significant factor. Our main differentiation of funding risks is by the nature of the depositor:

- **Wholesale Funding Risk:** The risk of being unable to refinance via short term deposits in sufficient amounts or reasonable terms
- **Retail Deposit Risk:** The risk of sudden volume reductions in deposits, or that required deposit rates to maintain volumes will rise unexpectedly in response to market or firm events

Funding risk concerns both availability and price of funds and the underlying risk factors can be split along the following hierarchy:

- Firm-specific events that affect the market perception of credit worthiness, essentially widening the credit spread of the firm for idiosyncratic reasons
- Sector-specific events (contagion / aversion due to events in similar firms), widening of the credit spread of all financial firms
- Market wide events (a more generalized liquidity squeeze), widening of credit spreads across all corporates

## Operational Risk

Operational risk concerns threats to the operations of the firm. Adopting the structure of the regulatory taxonomy (but excluding legal risk)

- Physical Damage Risk and System Failure: The risk of unexpected loss as the result of physical damage to the firm's assets or failure of its systems
- Business Execution: The risk of loss as a result of poor or erroneous execution of regular business tasks. Distinct from Performance Risk, i.e., the ability to meet agreed business targets
- Internal Fraud Risk: The risk of unexpected loss as the result of fraudulent action of persons internal to the firm
- External Fraud Risk: The risk of unexpected loss as the result of fraudulent action of persons external to the firm
- Employment Practices Risk: The risk of unexpected loss as the result of employment practices followed by the firm which may not meet applicable laws and standards

Operational risk is generally a discrete risk type and is thus decomposed into the

- Likelihood of operational risk event (e.g. a hazard model). Regulatory AMA models simplify to 1-yr estimate.
- Loss impact of operational risk event

In the context of the Advanced Measurement Approach (AMA), each one of the event types is modeled by a loss generating process (typically a generalized point process) that produces loss events. The process is calibrated using internal and external data and may be further augmented by subjective expert interventions. There is no linkage to business process characteristics besides that obtained via the segmentation of the empirical data by business line.

Aggregation of Operational Risk events is notoriously difficult. The primary reason is that a purely empirical estimation of the dependency structure of disparate fat-tailed processes is very challenging. This is aggravated by the lack of any intuitive explanatory power of the elementary model components.

## Franchise Risk

Franchise risk captures the most elusive and most difficult to quantify risks, namely the impact of external or internal risk factors on the perceived long term franchise value of the firm. Franchise risk factors can be both internal (legal problems or strategy failures) or external (changes in the competitive and social environment).

Franchise risk has strong correlation with reputation risk, but we consider the latter to be parallel outcome of certain events rather than a separate risk factor. A list of the most common threats to the franchise would include:

- Legal Risk: The risk of losses arising from an unintentional or negligent failure to meet professional (legal, fiduciary) obligations to clients. Largely overlaps with so-called Conduct risk.

- **Business Model Disruption Risk:** The risk that competitors develop drastically alternative business models (e.g., new products or reduced cost structures) rendering the firm's operations non-competitive
- **Political and Regulatory Risk:** The risk that the broader environment in which the firm operates will develop in directions adverse to the firm's business plan (e.g. significant changes to the applicable tax framework, the type and amount of regulation, or change to what are considered socially acceptable business practices)

## Contractual Risks

Contractual risks are linked to existing market positions in securities or derivatives, lending products, internal and external performance contracts etc.

Contracts can be categorized as assets or liabilities, may have a funding component or be "off-balance sheet". We further classify them by the risk factors underlying each instance. Contract based risks are easier to analyze because the contracts typically stipulate certain cashflows (the objective) and risk factors are the uncertainties that may prevent the contractual payoffs from materializing.

## Insurance Risks

This subcategory includes risks linked to underwritten liabilities for any of the defined types of insurance policies. Insurance risks are unique in the taxonomy in that they are very specifically *underwritten* (the firm seeks to assume the specific risk in exchange for a premium). For this reason the insurance risk taxonomy is also largely a business line taxonomy.

- **Life Insurance:** Risks linked to the underwriting of life insurance policies, such as deviations from standard mortality rates or lapses and revisions to policies
- **Health Insurance:** Risks linked to the underwriting of health insurance policies, such as deviations from standard sickness rates or lapses and revisions to policies
- **Motor Insurance:** Risks linked to the underwriting of motor (car) insurance policies, such as deviations from standard claim rates or lapses and revisions to policies
- **Property Insurance:** Risks linked to the underwriting of property insurance policies, such as deviations from standard claim rates or lapses and revisions to policies
- **Liability Insurance:** Risks linked to the underwriting of liability insurance policies, such as deviations from standard claim rates or lapses and revisions to policies

Models for actuarial risk are similar to operational risk models and are composed by

- Probability of claim models (typically statistical)
- Loss amount models

## Credit Risk

Risks arising from credit events (default, bankruptcy) associated with a legal entity reneging on its contractual obligations (for payment). Hence credit assets differ by the legal entity involved, but also the type of product (how funds are disbursed, whether there is security etc).

Credit risk is a discrete risk type and is thus decomposed into

- Probability of default. The risk of a credit event. Typically a credit term structure. Regulatory credit models simplify to 1-yr estimate
- Exposure at default. The risk that the exposure at default may be differ from current exposure.
- Loss given default. Uncertainty about the loss given a credit event (complementary to recovery risk)
- Credit Loss Dependency. Uncertainty about joint default events (correlation, dependency or contagion).

Credit Risk Models can be statistical, theoretical, market or expert based. The traditional classification of credit risk is along the lines of a business line taxonomy (retail, corporate etc). From our perspective the nature of the obligor or credit product is a further sub-classification of the above classes: E.g. a model for sovereign probability of default may have different qualitative characteristics versus a retail client.

## Client Optionality Risks

Risks in products with option style features (non-linear payoffs). When options are traded in exchanges or OTC the corresponding risks are captured under market risk. The primary reason this class is treated separately is that for some products either the size of the positions or low market liquidity makes the exercise behavior of clients or counterparties a distinct risk that must be modeled separately and without reference to market observables.

The most common types of optionality embedded in banking products are

- Prepayment Risk: The risk that clients who borrowed funds will prepay these funds earlier than expected due to a reduction in prevailing interest rates
- Drawdown Risk: The risk that clients with credit lines will draw on these at amounts different than expected due to their individual or market circumstances

Models for these risks are typically of behavioral type (based on historical behavior versus given market environment).

Sometimes in academic literature credit risk is treated as an optionality risk too (the obligor has the option to default). While this may be strictly true, the significant impact of default on the economic and reputation status of the borrower means that exercise behavior more complicated.

Another complication is that credit risk interferes with other optionality risk (a pre-paid mortgage cannot default) and some modeling frameworks adopt a competing risks approach where the contract status is modeled jointly versus these distinct exercise possibilities.

## Market Risk (Trading and Banking Books)

Risks linked to traded markets positions or banking book positions affected by market price level, volatility, correlations or liquidity. The traditional taxonomy of traded market risk (equities, rates etc) inherits from business lines (the specialization of a trading desk) and is not the most informative classification choice as these different markets share high level risk characteristics.

In most markets risk arises from either the direct trading of securities (e.g., equities, bonds), physical assets (e.g., oil, metals) or via derivative contracts (exchange based or over-the-counter).

Market price risk is generally a continuous risk, with the exception of jumps around times of low liquidity (market breakdown). A more detailed set of categories includes:

- Price risk (level, volatility of a given market)
- Correlation risk (correlations of different markets)
- Market liquidity and jump risk, i.e., the risk of wide bid/ask spread or even complete market dislocation
- Valuation risk applies to illiquid products which may require unobservable and model based parameters for marking-to-market
- Hedging risk applies to illiquid products when certain elements of market risk are to be hedged away on the basis of model derived hedges. Includes basis risk

Valuation and hedging risks are examples of model risk. They are sometimes included as a form of operational risk (i.e., deemed to be a consequence of business process failure around model validation). This is conceptually not correct. While certain types of errors around models are certainly of an operational nature, model risk is intrinsic to and cannot be eliminated.

The main aggregation model for market is of course the venerable Value-at-risk framework. It consists of a dependency framework for the set of markets being traded along with a revaluation framework for all positions

## Human Resource Risks

The internal human factor was already encountered in operational and franchise risks. Here we are concerned with instances where the risk is linked to contracts. This occurs primarily in two areas, agreements with current employees and liabilities to these previously employed.

- Performance Risk: The risk of adverse developments to the firm's human resource pool (key man risk / defections, under-performance) with impact to the firm's revenue (and franchise value)
- Employee Pension Liability Risk: The risk of unexpected required contributions to employee pension funds that cannot meet their required solvency standard on standalone basis

## Aggregation Risks

Aggregating all the risks facing the firm requires a dependency framework for all the component risks. This is not generally available for all possible risks, but certain groups of risks can be studied together.



# Bibliography

- [1] O. Foshaug and P. Papadopoulos. Open Risk Application Programming Interface. 2015. [Link](#).
- [2] Basel Committee on Banking Supervision. Review of the Principles for the Sound Management of Operational Risk. 2014.
- [3] T. Schuermann M. Ames and H.S. Scott. Bank capital for operational risk: A tale of fragility and instability. 2014.
- [4] M. Hellwig P. Pfleiderer A. Admati, P. DeMarzo. Fallacies, irrelevant facts, and myths in the discussion of capital regulation: Why bank equity is not socially expensive. 2013.
- [5] Wikipedia. COSO: Committee of Sponsoring Organizations of the Treadway Commission. [Link](#).
- [6] Basel Committee on Banking Supervision. Basel II: International Convergence of Capital Measurement and Capital Standards: A Revised Framework. 2006.
- [7] Rene Doff. Defining and measuring business risk in an economic-capital framework. 9(4):317–33, 2014.
- [8] van I. Eeghen and P. Klaassen. *Economic Capital - How It Works, and What Every Manager Needs to Know*. Elsevier Science, 2010.