

Quality, Risk and the Taleb Quadrants

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Abstract

The definition and the management of quality has evolved and assumed a variety of approaches, responding to an increased variety of needs. In industry, quality and its control has responded to the need of maintaining an industrial process operating as “expected”, reducing the process sensitivity to uncontrolled disturbances (robustness) etc. By the same token, in services, quality has been defined as "satisfied customers obtaining the services they expect". Quality management, like risk management, has a general negative connotation, arising from the consequential effects of “non-quality”. Quality, just as risk, is measured as a consequence resulting from factors and events defined in terms of the statistical characteristics that underlie these events. Quality and risk may thus converge, both conceptually and technically, expanding the concerns that both domains are confronted with and challenged by.

In this paper, we analyze such a prospective convergence between quality and risk, and their management. In particular we emphasize aspects of integrated quality, risk, performance and cost in industry and services. Throughout such applications, we demonstrate alternative approaches to quality management, and their merging with risk management, in order to improve both the quality and risk management processes. In the analysis we apply the four quadrants proposed by Nassim Taleb for mapping consequential risks and their probability structure. Three case studies are provided, one on risk finance, a second one on risk management of telecommunication systems and a third one on quality and reliability of web based services.

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1. Introduction

Quality and risks are neither topics of recent interest nor a fashion. They are, and promise to remain, problems of interest essential to consumers, firms and to nations' competitiveness. The "American Way" has traditionally been based on excellence in manufacturing, product innovation, responsiveness to consumers and making money. The test of the market, which brings firms to profitability and others to oblivion, is also a pervasive part of the American scene. It is these same market tests, expanded by global supply chains, manufacturing technology and competition that have raised the priority of quality and risks in industrial and business strategies (Daudin and Tapiero, 1996, Tapiero, 1996)..

Quality, as a subject, has been developed, among others, by Shewhart, Deming, Feigenbaum and Juran. Joseph M. Juran's contributions include structured process improvement and quality by design in order to achieve lower operating costs and higher revenues, thus higher profits. Quality improvement, quality planning and quality control are known as the Juran's trilogy which is at the basis of quality management and Six Sigma (Juran, 1986, 1989). Godfrey and Kenett (2007) review Juran's contributions and emphasize the need to integrate information from different sources to achieve better decision making. Here we focus on the integration of quality and risk, as an approach leading to increased insights and thereby better management decisions.

A risk and quality convergence underlies consumers and firms motives, seeking the means to prevent and control their consequential effects—whether adverse or beneficial. While risk defines the consequences of an adverse event, quality is defined mostly as an “unrealized” expectation, imbedded in a preference for specific characteristics of quality or its “concept” expounded for by consumers. In this sense, both quality and risk have focused on the adverse consequences and are subject to probabilities that define their occurrence (albeit, both recognize at time the lack of predictability of these events). Further, both take into considerations individuals, firms and society at large. The issues relating to who bears the risk (as well as who bears the responsibility for producing a non-quality product) if it occurs, is essential and important in both cases. Risk and non-quality can result from many causes, both internally induced (by inappropriate training, contradicting organizational goals etc.) or occurring externally (for example by water quality or economic conditions). Their consequences however may be diverse, affecting various parties. When risk is internally induced, it may be due to low capability operations, faulty operations, human errors and failures or misjudgment. See for example aircraft accidents and aircraft incidents (Kenett and Salini, 2008). Similarly, when risk is endogenous, it results from “counter-party” or systemic risks. When it occurs externally, its consequences result from uncontrollable events or events we cannot prevent that can be handled as a risk. Preventive efforts and insurance can be used to mitigate their consequential effects. In general, a definition of risk and quality, involves the following factors (Tapiero, 2004, 2006):

- **Consequences**, bourn individually or collectively, by the persons responsible for the adverse risk or quality event, or not. This represents a future event.
- **Probabilities** and their distribution, assumed known, partly known or not known, consisting of random (systemic) recurrent, persistent or rare events. These represent past experience.
- **Detectability**, reflecting our ability to identify the risk. Low delectability obviously requires more aggressive mitigation strategies.
- **Individual preferences and risk attitudes**, representing the costs, subjective and psychological effects and needs and a personal valuation (price) of the needs and their associated consequences.
- **Collective and shared effects**, including effects on society at large (or risk externalities) and the manners in which these risks are negotiated and agreed by the parties involved—either through a negotiated exchange or through a market mechanism.
- **Pricing of these risks** (and quality), usually based on an exchange within an organization (such as a supply chain, a franchise, or as negotiated in typical industrial contracts, etc.) or occurring in specific markets (financial or otherwise) where such risks are exchanged.

As a result, risk and quality share many common concerns. While quality is in many cases derived from the risks imbedded in products or processes, reflecting consumers and operational concerns for reliability design, maintenance and prevention, statistical quality control and statistical process control, it is also concerned with the management of variations, total quality management or six sigma. Similarly, the many tools used in managing risks seek to define and maintain the quality performance of organizations, their products, services and processes.

Both risks and quality are relevant to a broad number of fields, each providing a different approach to their measurement, their valuation and their management which are motivated by psychological, operational, business and financial needs and the need to deal with problems that result from the uncertainty and their adverse consequences. Both uncertainty and consequences may be predictable or unpredictable, consequential or not and express a like or a dislike for the events and consequences induced.

Risk and quality are thus intimately related, while at the same time each has, in some specific contexts, their own particularities. When quality is measured by its value added and this value is uncertain or intangible (as it is usually the case), uncertainty and risk have an appreciable effect on how we deal, we measure and we manage quality. In this sense, both risk and quality are measured by "money". For example, a consumer may not be able to observe directly and clearly the attributes of a product. And, if and when he does so, this information might not be always fully known, nor be true. Misinformation through false advertising, unfortunate acquisition of faulty products, model defects, etc. have a "money effect" which is sustained by the parties (consumers and firms) involved. By the same token, poor consumption experience in product and services can have important financial consequences for firms that can be subject to regulatory, political and social pressures, all of which have financial implications. Non-quality, in this sense is a risk that firms assess, that firms seek to value and price and that firms manage to profit and avoid loss. Quality and risk are thus consequential and intimately related. The former (quality) is delivered and induces a risk while the latter (risk) imbeds both some of the tools we use to defined and manage quality. Finally, both have a direct effect on value-added and are a function of the presumed attitudes towards risk and the demands for quality by consumers or the parties involved in an exchange where either quality or risk (or both) prime..

The approaches we use to manage and share risks, both for industrial and service firms and for customers-consumers, are immensely important. These are essential facets of both the process of risk and quality management. Warranty contracts, service contracts, liability laws, statistical quality control etc. are some of the means available to manage these risks, and thereby quality (for example, see Tapiero, 1981, 1994, 1995, 1996, 2005, Reyniers and Tapiero, 1995, 1996, Lee and Tapiero, 1986, 1989 as well as other articles by Tapiero listed as references). And vice versa, managing risks through preventive measures, through total quality management and related techniques improve the prospects of quality as well. Of course, each situation may have its own particularities and therefore may be treated in a specific and potentially different manner. For example, environmental pollution and related issues have both risk and quality dimensions deeply intertwined that may be treated differently than say the quality and the risks of services (see also Tapiero, 2004, 2005). As another example consider the definition of service quality. A gas station provides several services beyond the supply (usually at a regulated price) of fuel. Hotels provide a room and various associated services. As a result, the quality of service may be defined mostly in terms of intangibles, often subjective and therefore difficult to define—unless their satisfaction can be specified by a risk (probability) event. Unlike quality in manufacturing, the quality of services depends both on the "service provider" and the "serviced customer" with their associated risks. Poor service is usually reflected by customer dissatisfaction and eventual churn.. Service delivery needs not be consistent thereby providing the right service, every time. Comparable notions of in industry are addressed by considering machine breakdowns or improperly performed functions.. Furthermore, the quality of service and its measurement are dependent and at times subjective. A service provider who is inspected might

improve the quality of service delivery. A sense of lack of controls might result in poor service delivery. Such behavior introduces a natural bias in the measurement of service efficiency and its quality which can benefit from a probabilistic and risk-based approach. These specific characteristics have an important impact on the manner in which we conceive and manage both the quality of service and their associated risk and their consequences to individuals, firms and society.

A quality-risk convergence is applicable to many fields spanning financial services, operational risks, marketing, engineering, health, wellness, supply chains, financial services, franchises, environmental and industrial management, etc. They are of importance in all fields and situations where uncertain events and their consequences are considered and where persons, agents or organizations operate in the expectation that they get what they contracted or paid for. Issues resulting from such concerns, both academic and practical, are of course not new. Financial economics, for example, deals extensively with hedging problems in order to reduce the risk of a particular portfolio through a trade or a series of trades, or contractual agreements reached to share and induce risk minimization by the parties involved. In this special context, risk management consists in using financial instruments to negate the effects of risk. A quality performance would then be a satisfied investor, predictably earning money, or at least not losing it.

Such concerns are similar to those faced by a process control manager who seeks to reduce and manage variations to a level where a consequential error in the process will occur with extremely small probabilities or have no consequences (robustness) at all (see Hsu and Tapiero 1988a, 1988b). The Six Sigma quality level of 3.4 defects per million opportunities is such an example. A concern for TQM (Total Quality Management) has been similarly expanded by a concern of ERM (Enterprise Risk Management) in Insurance and Actuarial industries. A recent survey of actuarial scientists and practitioners, concerned for the quality of their organizations suggested a broad definition of Enterprise Risk Management which imbeds an equal concern for quality: "The process by which organizations in all industries; assess, control, exploit, finance and monitor risks from all sources for the purposes of increasing the organization's short and long term value to its stakeholders" (Casualty Actuarial Society, 2005).

The following sections provide a conceptual framework integrating quality and risk. In particular we emphasize Taleb's four quadrants as a framework to systematize a quality-risk convergence (see also, Taleb's Black Swan, 2007). Such a framework has both managerial and technical connotations that do not negate the fact that risk is complex, at times unpredictable and at times of extraordinary consequences. A convergence of quality and risk will enrich two important and creative areas of research and practice, augment transparency and provide a measurable value of quality and a better assessment of what we mean when we define quality and are or not able to do. In addition, this paper recognizes the limits of models we use in managing both quality and risk and therefore the limits of any model that may be propounded as providing a solution to a real problem. Applications are used to partially highlight our approach and provide some motivation to dealing with the quality-risk convergence. In general our goal is to better generate knowledge based on information and data (see Kenett, 2008).

2. On the Management of Quality, Black Swans and Taleb's Four Quadrants

Important consequential risks are typically unpredictable and rare. While predictable risks may be prevented, unpredictable risks tests our resilience and our ability (agility) to respond. Based on this premise, Nassim Taleb's metaphor: "A Turkey fed for a 1000 days, every day, confirms that the human race cares about its welfare with increased statistical significance. On the 1001st day, the turkey has a thanksgiving surprise. its total demise. Similarly, the presumption that good times are forever, and acting as if they were to last forever, can be remarkably irresponsible from a risk management viewpoint. The financial meltdown of 2008 may attest to such risks with an aggregate fate of close to 1000 financial institutions (including busts such as FNMA, Bear Stearns, Northern

Rock, Lehman Brothers, etc.) who lost over 1 Trillion dollars on a single error, more than was ever earned in the history of banking. For more on turkeys and black swan rare events see Taleb, 2009 and Taleb and Tapiero, 2009. In this sense, Taleb contribution in “Black Swan” risks and “Fooled by Randomness” have contributed to a greater focus of risk analysis and its management on the rare and the unpredictable spectrum, compared to a focus on the common and “normal” risks statistical and financial risk analyst have traditionally focused on. To a large extent, similar problems have confronted the management of quality. From control in the early 20th century to risk prevention in the latter part of the 20th century and to robustness and Quality by Design (see Kenett and Zacks, 1998, Nasr, 2007, Kenett et al, 2008, Kenett and Kenett, 2008). For aspects of risks in quality management see Tapiero, 2003-2009. The latter approach, robustness, emphasizing greater sensitivity to model defects and the importance of the mis-assumptions that underlie, necessarily, traditional models used to manage quality. Thus, both risks and quality have converged in their recognition that models are not reality but a segment—often very partial, and visionary of what reality might in fact be.

To confront this evolving risk reality, Taleb has suggested a mapping randomness and decision making into a quadrant with two classes of randomness and decisions. The type of decisions referred to as “simple” or “binary” lead to decisions such as “very true or very false”, “matters or does not matter”. By the same token, statistical tests in the control of quality may state, “A product is fit for use or the product is defective”. Statements of the type “true” or “false” can then be stated with some confidence interval. A second type of decisions is more complex, emphasizing both its likelihood of occurrence and its consequences.

By the same token, two layers of randomness, very distinct qualitatively and quantitatively are suggested by Taleb. A first layer is based on “forecastable events”, implied in finite variance (and thus thin tail probability distributions) and a second based on “unforecastable events”, defined by probability distributions of fat tails. In the first domain, exceptions occur without significant consequences since they are predictable and therefore preventable (or diversified in financial terms). The traditional random walk, converging to Gaussian-Poisson processes provides such an example. In the second domain, large consequential events are experienced which are more difficult to predict. “Fractals” and infinite variance (Pareto-stable and chaotic) models provide such examples (for example, see Benoit Mandelbrot 1982). Extensive studies based on range to standard deviation statistics or R/S analysis in time series (Hurst 1951), have also pointed out to a statistical approach to detect such situations (see also Vallois and Tapiero, 1997, 2001, 2007, 2009). These models presume that random processes in nature (or in financial markets) do not follow necessarily a Gaussian distribution. Thus to relieve the constraining assumption of such assumptions, weaker forms of underlying risk probability processes are suggested such as Lévy stable distributions (or Levy processes) that have both leptokurtic distributions having potentially infinite variance. For example, in commodity prices, Mandelbrot found that cotton prices followed a Lévy stable distribution with parameter α equal to 1.7 rather than 2 as it is the case in a Gaussian distribution. “Stable” distributions have the property that the sum of many instances of a random variable follows the same distribution (and therefore, aggregates have the same distribution of their individual events—a fallacy which can be misleading in financial decision making, (see Taleb and Tapiero, 2009).

These two dimensions form a map with four quadrants (Table 1), each quadrant appealing to its own methods to deal with the challenges that each quadrant is raising. For example, the first quadrant: Simple binary decisions, in cases of thin tailed distributions (with predictable events), lends itself to effective statistical analysis which we tend to emphasize because of our ability to treat such problems successfully. Most real problems however do not fall in this quadrant. The second quadrant consists of simple decisions, confronted by “heavy tailed distributions”. Currently important efforts are devoted to problems of this sort in finance which assume that financial markets are incomplete or the underlying “randomness” has a leptokurtic bias” combined with extreme volatilities (in which financial markets seem to react chaotically, augmenting asset prices volatility). The third quadrant deals with complex decisions in thin tailed distributions where statistical methods work surprisingly

well. In such cases, Monte Carlo techniques, appropriately designed have provided an efficient mean to investigate and solve problems related to the third quadrant. In this sense, while the first three quadrants may lead to complex risks analysis problems, these problems may adopt both modeling and computational techniques which can be used to remove and manage some of their associated complexity and uncertainties

The risk-challenge lies in the fourth quadrant however, combining complex decisions with heavy tailed (events unpredictable) distributions. Such situations recur when confronted with a Black Swan (although rare, existing nonetheless). Similarly, a turkey (or a Bank's CEO), consuming all it can (assuming ever greater risks to make ever greater profits) is confronted by a rare and recurring event (one day each year) as that met by the Turkey on Thanks Giving Day. By the same token, the Bank CEO may at last be confronted with the well known adage that "you can fool most of the people most of the time, perhaps some may be fooled all of the time, but not all can be fooled forever all of the time". Eventually, short sightedness and greed have their own consequences. These problems are important equally in the control and the management of quality, reliability, safety and all matters where risks are prevalent. In particular, in large network based and complex dependent systems, the interactive behavior of these systems may lead to fractal models characterize by both unpredictability and catastrophic consequences.

Domain\Application	Simple Decisions	Complex Decisions
Thin tailed "Gaussian-Poisson" Distributions	I. Classical Statistics	II. Complex Statistics
Heavy tailed or unknown "Fractal" Distributions	III. Complex Statistics	IV. Extreme fragility ("Limits of Statistics")

Table 1: The Four Quadrants of N. Taleb (Adapted from Taleb, 2008)

Modern industrial organizations, in manufacturing and services, are characterized by increased networking and dependence and are subjected to increased competitive pressures, rising customer expectations and by a growth of complexity. While these expectations may mean to seek greater "predictability" (i.e. and equivalently, greater quality), the complexity of systems and products may not be able to meet the demand for such "predictability". A growth of complexity and interdependence might overwhelm our physical capacity to circumvent such complexity. Such phenomenon is well documented in Ashby's second law of cybernetics (The Law of requisite Variety, see all also Tapiero, 1989, 1994). Management teams in global supply chains, on all five continents, are striving to satisfy and delight their customers while simultaneously improving efficiencies and cutting costs. In tackling this complex management challenge, an increasing number of organizations have proved that the apparent conflict between high productivity and high quality can be resolved through improvements in work processes and quality of designs (robustness) that recognizes the limits of in-house modeling compared to in real life performance. This experience is provided by an increased maturity acquired by facing to increasingly challenging and demanding customers. Different approaches to the management of organizations have been summarized and classified using a four-step Quality Ladder (see Kenett and Zacks, 1998, Kenett et al, 2008). The four management approaches are 1) Fire Fighting, 2) Inspection, 3) Process Control and 4) Quality by Design and Strategic management. In parallel to the management approach, the Quality Ladder lists quantitative techniques that match the management sophistication level (see Figure 1). This matching is similar in scope to Taleb's four quadrants. Here however the scope is to match management maturity with the statistical techniques that can be effectively used by the organization.

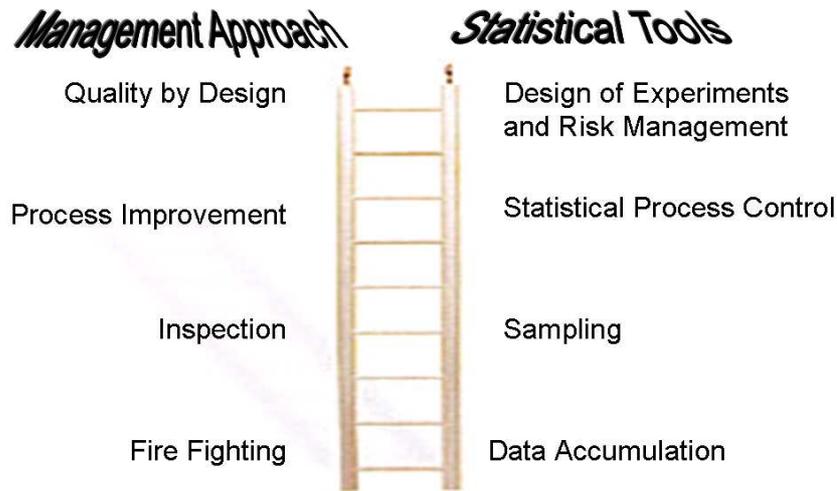


Figure 1: The Quality Ladder (Adapted from [15])

Managers applying reactive fire fighting can gain from basic statistical thinking. The challenge is to get these managers to see the value of evolving their organization from a state of data accumulation to data analysis and proactive actions turning numbers into information and knowledge. Managers who attempt to contain quality and inefficiency problems through inspection and 100% control can increase efficiency by using sampling techniques. Their approach is more proactive than fire fighting but the focus on end products, post factum, can be very expensive. Sampling inspection can reduce these costs provided proper statistical analysis is used in order to establish sample sizes for inspections. The decision of what to test, when and where should be assessed statistically so that the performance of the approach is known and adequate. More proactive managers, who invest in process control and process improvement, can take full advantage of control charts and process control procedures. Process improvements and risk prevention affect “how things are done”, thereby affecting both cost and quality in a positive way. At the top of the Quality Ladder is the Quality by Design (robustness) approach where up front investments are secured to run experiments designed to optimize product and process performance in a real setting, insensitivity to “model defects” is sought. At such levels of management sophistication, robust experimental designs are run, for instance, risk management and reliability engineering are performed routinely, and risk estimates are compared with field returns data to monitor the actual performance of products and improve the organizations’ predictive capability and “predictable real performance”. Efficient implementation of statistical methods requires a proper match between the management approach and implemented statistical tools however. More generally, the *Statistical Efficiency Conjecture* discussed in Kenett et al (2008) states that organizations increasing the management sophistication of their management system, moving from fire fighting to Quality by Design, enjoy increased benefits and significant improvements with higher returns on investments. In this sense, recognizing the consequential effects of risks is not a theoretical exercise but a rational and economic consideration to reckon with in the management of quality.

The move up the Quality Ladder is pursued by management teams in different industries and in different manners. For example, in electronic systems design, mechanical parts manufacturing, system assembly software based services and chemical processes use different approaches imbedded in their experience and traditions. A particular industry where such initiatives are driven by regulators and industrial best practices is the pharmaceutical industry. In August 2002, the Food and Drug Administration (FDA) launched the pharmaceutical current Good Manufacturing Practices (cGMP) for the 21st century initiative. In that announcement, the FDA explained the agency's intent to integrate quality systems and risk (consequential) management approaches into existing quality programs with

the goal of encouraging industry to adopt modern and innovative manufacturing technologies. The cGMP initiative was spurred by the fact that since 1978, when the last major revision of the cGMP regulations was published, there have been many advances in design and manufacturing technologies and in the understanding of quality systems. This initiative created several international guidance documents that operationalize this new vision of ensuring product quality through “a harmonized pharmaceutical quality system applicable across the life cycle of the product emphasizing an integrated approach to quality risk management and science”. This new approach is encouraging the implementation of Quality by Design and hence, de facto, encouraging the pharmaceutical industry to move up the Quality Ladder (see Kenett and Kenett 2008 and Nasr, 2007). The Capability Maturity Model Integration (CMMI) invokes the same principles for the software and systems development industry (CMMI, 2002).

Quality, as practiced traditionally and in most organizations, is focused on problems detection and correction. Increasingly, however, preventive efforts are made to manage of quality. Problem correction, while essential, only serves to remove the defects that have been embedded in the product by development and production process. When properly organized for continuous improvement and quality management, organizations focus on problem prevention in order to improve the quality of the product and improve their competitive position. Continuous improvement, as a company wide management strategy, is a relatively recent approach. For thousands of years improvement and innovation was slow. New scientific breakthroughs often occurred by chance with an “intelligent observer” being in the right place at the right time. As significant events occurred, someone asked why, and after some experimentation, began to understand the cause and effect uncovered by that observation. The discovery of X rays by W. C. Roentgen is a classic example. Champagne was also discovered in that way. By the late 1800s, an approach to centrally plan innovation and improvement was beginning to appear. Thomas Edison built his laboratory in 1887 and conducted thousands of experiments. Throughout the twentieth century several industrial, academic, and government laboratories, often employing tens of thousands of researchers, were established. The art and science of experimental design became widely used to drive improvements in products and processes, and in developing entirely new products and services that are far more responsive to customers. In the latter half of the twentieth century, another phenomenon took place, first in Japan and then quickly in other parts of the world. Large numbers of employees in organizations were taught the basics of the scientific method and were given a set of tools to make improvements in their part of the company. They were empowered to introduce changes in processes and products in order to achieve improved production and product performance. Total Quality Management and Six Sigma are examples of this approach (Godfrey and Kenett, 2007).

Problem prevention (just as risk management) has two aspects: (1) Preventing recurrence of existing problems, and (2) preventing introduction of new problems. In such cases, problem prevention results in quality improvement considered to be of two types: reactive (driven by problems) and proactive (driven by the desire to improve quality and efficiencies). Reactive quality improvement is the process of understanding a specific quality defect, fixing the product, and identifying and eliminating the root cause to prevent recurrence. Proactive quality improvement is the continual cycle of identifying opportunities and implementing changes throughout the product realization process, which results in fundamental improvements in the level of process efficiency and product quality. It is a continual process sometimes primed by problem correction initiatives. A reactive causal analysis of a quality defect will sometimes trigger a change in a process, resulting in a proactive quality improvement that reduces defect levels.

As mentioned in section 1, Joseph M. Juran made significant contributions to the establishment of proper structures for quality improvement (Juran, 1986, 1989). Juran's Quality Trilogy of *Plan*, *Control* and *Improve* is possibly the most simple, complete, and pure representation of managing for quality ever devised. Juran found it useful to teach about managing quality using an analogy that all managers easily understand - managing budgets. Financial management is carried out by three

managerial processes: budget planning, financial control, and cost reduction. Managing quality makes use of the same three fundamental processes of planning, control, and improvement. The trilogy presented in Figure 2 exemplifies the essence of Quality with a capital Q, providing a ladder for quality manager to climb:

- Quality Planning: The process for designing products, services, and processes to meet new breakthrough goals
- Quality Control: The process for meeting goals during operations
- Quality Improvement: the process for creating breakthroughs to unprecedented levels of performance.

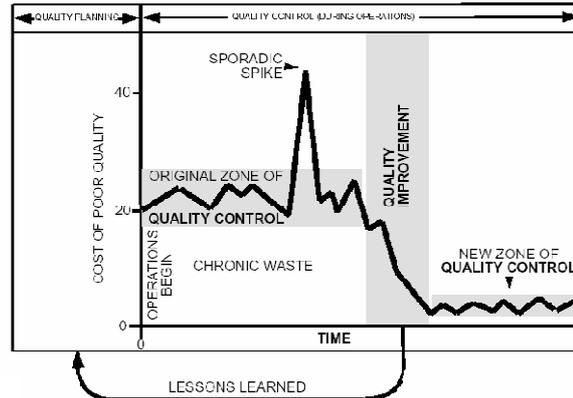


Figure 2: The Juran Trilogy (Adapted from Juran, 1986)

While Juran's Trilogy is simple and accurate, it is important to understand that the elements represented are infinite and layered. To properly implement the trilogy in products, services, and processes, one must understand that the trilogy is three dimensional and limitless, resulting in an endless improvement process. For example, the Quality Planning of a new market offering will consist of Quality Planning for products, services, processes, suppliers, distribution partners, etc., with impact on the delivery of the new offering. On another layer, this phase must also plan for the support and maintainability of the offering. On yet another layer, the planning phase must account for design and integration of data collection, control, improvement processes, people, and technologies. Finally, the planning phase must design the evaluation of the planning phase itself. In this simple example, we see four layers of Quality Planning. This phase will typically be iterated and improved with every cycle and within each cycle. The same is true of all other phases. Such an approach however is incremental, based on a recurrent and predictable process fed by a (Bayesian) experience that arises from “learning by doing”. With this methodology, Taleb’s last quadrant would not fare well however. Nevertheless, striving for zero defects, perpetual improvement, prevention, appropriately combined with robust design and risk recovery provides an avenue to meet the challenges of the fourth quadrant

In the sequel, we show, with examples, how combined considerations of quality and risk management can be implemented, this demonstrating the benefits of the convergence between risk and quality management. The examples we use are from Web based Service Oriented Architecture applications, from a network control of a telecommunication equipment supplier and a price advertising campaign example.

3. Risk and Quality Applications and A Financial Convergence

a. Risk Management Applications to Service Oriented Architectures

Service Oriented Architecture (SOA) and Web Services (WS) technologies have received a significant attention recently. As an instance of standard-based implementation of SOA, WS has been widely applied in electronic business, embedded systems, game composition, and education systems. However, due the distribution of services on the Internet, the Quality of Service (QoS) and the various Operational Risks have been a concern which may prevent WS being applied in mission-critical applications. Among other techniques, testing is critical to assure the QoS of WS.

In SOA development, the Quality Assurance (QA) responsibility can be split among three parties: service providers who develop and host services; service brokers who publish services and allow dynamic discovery and binding of services; and service customers who build applications by searching services from brokers and remotely accessing services hosted on the providers' sites. This is different from QA in traditional software where QA team, which independent of the development team yet belong to same organization, is mainly responsible for software assurance. However, in SOA software QA, as more parties are involved in software composition, more parties will be involved in QA.

The dynamic and internet-based distributed computing features in WS present unique challenges to traditional risk management and testing techniques. New testing techniques need to be developed to address issues such as runtime assessment of services and workflow, just-in-time establishment in collaboration, and dynamic reconfiguration and re-composition. WS environment provides service registries and repositories that allow any service provider to submit any services at anytime. A service customer can search and select any published service as far as the service is available and meets the user requirements. Currently, few QA mechanisms are available for WS applications. To address the distributed and collaborative nature of WS testing, a test broker architecture was proposed in Bai et al (2007, 2008, 2009) Harel et al (2008), Kenett et al (2009). The test broker publishes test artifacts, simulates test execution, evaluates services and certifies services based on testing and evaluation results. The testing process is integrated in the collaboration SOA architecture of service publishing and discovery. A technique called Web Service Group Testing (WSGT) can be used to minimize the number of tests needed for comparative evaluation of participating services.

In WSGT, test cases are classified into various groups based on the test cases' capabilities to detect defects, called test case potency. Test groups are arranged hierarchically into layers. The higher the group locates, the higher its potency is. Different methods can be defined to rank test case potency, e.g., the dependency-based test case ranking. WS are tested though the layers. At each layer, services are evaluated against certain rule out strategies, based on a ranking model on the testing statistics. For example, the rank of a service is defined as a weighted sum of the number of tests a service fails in one level of the hierarchy. That is,

$$RL_k(s) = \sum_{i=1..nk} w_i F(s, t_i),$$

Where s is a service, t_i is a test in the layer, nk is the number of test scripts in the layer k , and w_i is the weight of test scripts t_i . And with a strict tolerance, the rule out strategy may be defined that a service cannot pass the layer unless it passes all the tests in the layer. That is,

$$RL_k(s) = \sum_{i=1..nk} w_i$$

With group testing, WS are simultaneously tested in bulk. With the windowing mechanism, it breaks WS into subsets called windows and testing is exercised window by window. Windowing allows for re-ranking of test cases and the re-organization of test hierarchy of the group testing at each window. It

improves test effectiveness with fewer but more potent tests and flexibly adjusts the test strategies across windows. In the windowing approach, the controller controls:

1. The selection of a group of WS of the window size.
2. The potency calculation of each test case.
3. The ranking and classification of test cases.
4. The organization of test cases into test hierarchies.
5. The testing of WS with the test cases through the test hierarchies.
6. The ranking of WS based on their testing statistics.
7. The ruling out of WS that do not meet the passing criteria.

The optimizer optimizes the test strategies from following aspects:

1. It adjusts the window size, and the window size control the rate of re-ranking. If changes are few, the refresh rate can be low.
2. It adjusts the potency of test cases based on recent test results to that the controller can re-rank and re-organize the test cases and choose the most potent test cases for testing on the new window.
3. It adjusts the WS ranking algorithm and rankings, and decides on the WS rule out criteria.

Figure 3 shows the architecture of the controller and optimizer. Different strategies can be defined to re-rank test cases and adjust window size. For example, a ranking difference (RD) is introduced as follows to show the fluctuation of test case potency changes.

$$RD_{i,i-1} = \sqrt{\frac{1}{n} \sum_{j=1,n} (PP_{tc_j,i} - PP_{tc_j,i-1})^2}, \text{ where,}$$

- 1) $RD_{i,i-1}$ is the ranking difference of two successive windows i and $i-1$.
- 2) $PP_{tc_j,i}$ and $PP_{tc_j,i-1}$ are the accumulated potency of a test case tc_j at two successive windows i and $i-1$.

The fluctuation of RD indicates the necessity to adjust the testing strategies. Multiple factors may result in RD fluctuation, such as:

- 1) The window size is too large or small and it needs to readjust the window to the best suitable size.
- 2) Test case aging. Test cases are published for a period of time and made known to the service providers who develop and test their services with the published test cases. Therefore, the potency of the test case decreased with time.

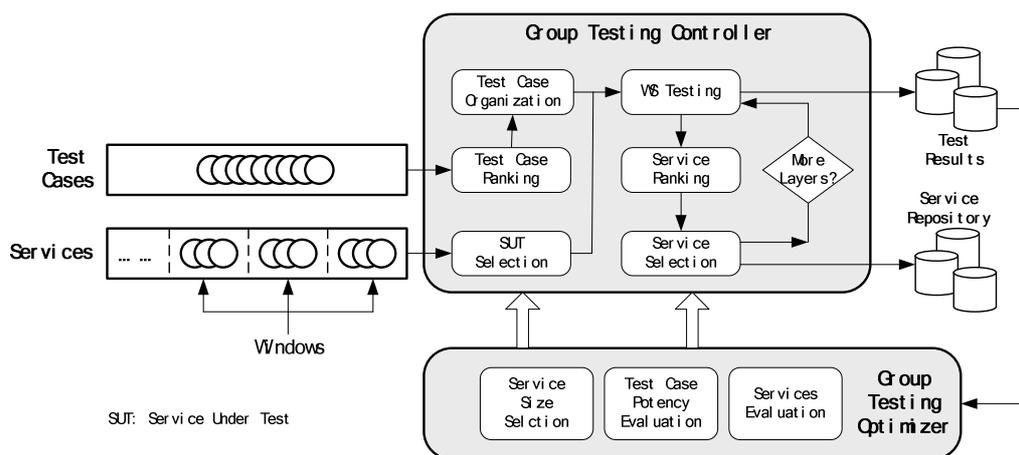


Figure 3: SOA environment testing framework (Adapted from Bai et al, 2007)

Another issue is that WS keep on changing, e.g., services can be updated and redeployed. Once updated, it is necessary to re-test and re-evaluate these services. Furthermore, new test cases can be submitted to the test repository, and older test cases may be modified or replaced as they are either no longer applicable or they have lost their power in detecting bugs. As a result, test plans may need to be re-organized with new test cases continuously to meet the changing environment. Therefore, an adaptive mechanism is necessary so that the test engine can respond to the changing environment and dynamically adjusting test strategies, such as test case ranking, categorization, layering method, WS ranking algorithm, WS rule-out criteria, and evaluation models. This application combines complex decisions with either thin tailed or heavy tailed distributions and therefore fits in either the first or third quadrant. The idea of test potency is directly linked to estimates of risk exposure addressed by the test cases. Such systems are critical to guarantee proper Quality of Service and allow for the expansion of Web Services. In this case risks are assessed to ensure quality, through a mechanism of Web Service Group Testing.

b. Quality and Risk Management of Telecommunication Services

In an application developed within the FP6 MUSING project (MUSING, 2006), 1000 PBX Telecommunication switching systems are continuously tracked through remote diagnostics producing log books or errors and warning messages. The data is merged with a data base maintained by technicians, a customer profile data base and records in the call center CRM system. The merged data set has been analyzed using Bayesian Networks which are providing, on line, a risk impact indicator for various problem types such as hardware, software and network interfaces and a severity impact index. The Bayesian Network establishes causality relationships between customer characteristics, the type of installed PBX, including size and number of peripheral equipments, risk events and their impact. For more on Bayesian Networks and causality mapping see Kenett, 2007. In addition to predictive estimates of risk the project has also implemented association rules for improved diagnostics and enhanced preventive maintenance (Kenett and Salini, 2008). A prototype of this operational risk management system is available in <http://musing-dev.metaware.it:8380/Tadiran/stats.html>. The application combines risk assessment techniques with advanced statistical process control techniques, to monitor the severity impact level from risks of telecommunication systems over time. One of the models used consisted of a Bayesian Estimate of the Current Mean (BECM) for estimating the current level of potential impact of currently experienced problems.

Risk scores of individual PBXs, by problem type, are recorded at discrete times $i = 1, 2, \dots$. The scores, X_i , are determined by the value of a base average level, μ_0 , and an unbiased error, ϵ_i . The higher the score, the higher the negative impact will be. Possible system deviations at start-up are modeled by having μ_0 randomly determined according to a normal distribution with known mean μ_T (a specified

target value) and a known variance σ^2 . At some unknown point in time, a disturbance might change the process average level to a new value, $\mu_0 + Z$, where Z models a change from the current level. This corresponds to either an increase or a decrease in risk impact for a specific PBX. The probability of having a disturbance between any two observations, taken at fixed operational time intervals, is considered a constant, p . Accordingly, we apply a model of at most one change point at an unknown location. The corresponding statistical model, for at most one change point, within n consecutive observations is as follows:

$$X_i = \mu_i + \varepsilon_i, \quad i = 1, 2, \dots, n,$$

where μ_i is the observation's mean and ε_i the measurement error, the at-most-one-change point model is:

$$\begin{aligned} \mu_i &= \mu_0, & i &= 1, \dots, j-1 \text{ and} \\ \mu_i &= \mu_0 + Z, & i &= j, \dots, n \end{aligned}$$

where j indicates that the disturbance occurred in the time interval between the $(j-1)$ st and j -th observations. $j = 1$ indicates a disturbance before X_1 , $j = n + 1$ indicates no disturbance among the first n observations. The Bayesian framework of this monitoring scheme is based on the following distributional assumptions:

$$\mu_0 \sim N(\mu_T, \sigma^2), \quad Z \sim N(\delta, \tau^2) \quad \text{and} \quad \varepsilon_i \sim N(0, 1) \quad i = 1, 2, \dots.$$

The parameters μ_T , σ^2 , τ^2 are assumed to be known and $N(\cdot, \cdot)$ designates a random variable having a normal distribution. The Gaussian assumption about ε_i requires that the raw data be scaled, to have conditional variance equal to 1. For n observations, let J_n denote the random variable corresponding to the index of the time interval at which a change occurred. It is assumed that the prior distribution of J_n is the truncated geometric, i.e.,

$$\begin{aligned} \Pr(J_n = j | p) &= p(1-p)^{j-1}, & j &= 1, \dots, n \\ &= (1-p)^n, & j &= n+1 \\ & & 0 &< p < 1 \end{aligned}$$

The assumption underlining the above is that disturbances occur at random according to a homogeneous Poisson process. $p(1-p)^{j-1}$ is the probability that the change occurred between the $j-1$ and j th observation and $(1-p)^n$ is the probability that the change has not happen up to the n^{th} observation. Finally, we assume that μ_0 , Z , J_n and ε_i are independent, for each n . The current mean μ_n can be written as

$$\mu_n = \mu_0 + I\{J_n < n\}Z,$$

where $I\{\cdot\}$ is an indicator variable, assuming the value 1 if the relation in brackets is true, and the value 0 otherwise. The procedure described in Zacks and Kenett (1994) and Kenett and Zacks (1998) computes analytically two statistics of interest to risk management.

1) The distribution of J_i , namely, the likelihood that a shift in distribution occurred in any time interval up to the current observation.

2) The distribution of μ_n , for example, percentiles of the distribution of the current mean.

We demonstrate the procedure with a simulation of 15 observations, with a change point at $J = 10$ with parameters $\mu_T = 0$, $\delta = 1.5$, $\sigma^2 = \tau^2 = 1$. The random values of μ_i ($i = 1 \dots 15$) are:

$$\mu_i = -1.91523, \quad i \leq 10 \text{ and } \mu_i = 0.53421, \quad i \geq 11$$

We therefore observe data with a shift in mean of 2.449 units, after the 10th observation. Table 2 lists the posterior distributions of J_i for $i = 7, \dots, 13$, that is before and after the shift. The maximal probabilities are indicated in bold and point to an estimate of where the shift has occurred. The probability of shift in the next interval represents the probability of a future shift. Up to the 10th observation interval, a shift is indicated as potentially occurring in the future. After the 11th observation the maximal probability of a shift is consistently pointing at the interval between observation 10 and 11.

i	7	8	9	10	11	12	13
X_i	-2.081	-2.837	-0.731	-1.683	1.289	0.5650	0.2560
1	0.0027	0.0028	0.0023	0.0025	0.	0.	0.
2	0.0057	0.0066	0.0037	0.0037	0.	0.	0.
3	0.0022	0.0023	0.0016	0.0016	0.	0.	0.
4	0.0072	0.0085	0.0029	0.0026	0.	0.	0.
5	0.0050	0.0054	0.0019	0.0017	0.	0.	0.
6	0.0047	0.0043	0.0017	0.0016	0.	0.	0.
7	0.0194	0.0039	0.0051	0.0055	0.0004	0.0001	0.
8	0.9606	0.0079	0.0078	0.0074	0.0011	0.0003	0.0002
9	-	0.9583	0.1583	0.0643	0.0964	0.0794	0.0927
10	-	-	0.8149	0.0139	0.0155	0.0149	0.0184
11	-	-	-	0.8952	0.8833	0.9052	0.8886
12	-	-	-	-	0.0032	0.0001	0.0001
13	-	-	-	-	-	0.	0.
14	-	-	-	-	-	-	0.

Table 2: Probability of a shift at any given time interval, at the i^{th} observation

i	7	8	9	10	11	12	13
X_i	-2.081	-2.837	-0.731	-1.683	1.289	0.5650	0.2560
$\mu_{.01}$	-2.937	-2.979	-2.746	-2.697	-1.789	-1.044	-0.911
$\mu_{.25}$	-2.328	-2.401	-2.193	-2.181	-0.587	-0.101	-0.094
$\mu_{.50}$	-2.085	-2.172	-1.947	-1.966	-0.113	+0.292	0.243
$\mu_{.75}$	-1.839	-1.941	-1.627	-1.735	+0.368	0.690	0.584
$\mu_{.99}$	-0.831	-1.233	0.872	-0.263	1.581	1.668	1.425
μ_i	-2.069	-2.161	-1.731	-1.918	-0.108	0.296	0.246

Table 3: percentiles of the distribution of the mean at any given time interval, at the i^{th} observation

Table 3 shows the percentiles of the risk impact scores. As expected, the procedure shows a decrease in the mean at the 11th observation. If we set an upper limit of 1 to the 99th percentile of the index, we see that usability has deteriorated at observation 11th so that some reactive risk mitigation procedure needs to be activated. This application was another example of a problem in quadrant II, complex decisions in the case of thin tailed distributions.

c. Risk and Quality Claims

The purpose of this example is to highlight a particular issue of quality and risk and an approach to price advertising quality claims (see also Tapiero 1981, 2000, 2005, 2009a). Ex-ante, we presume that a product quality, although defined by a density function (see also Posner and Tapiero, 1988, Tapiero, 2009b) is defined by its claims —setting the expectations for consumers for a performance and an expected satisfaction. Ex-post, however, experience compared to expectation defines quality. In this sense, the experience of quality is a random event which is a function of both the reliability-quality” of the production process and the many characteristics that defines a consumer attitude and his actual experience. Of course, “confirmation” of a quality claim by an experienced client contributes to repeat purchase while, “disappointment” contributes (in probability) to a consumer dissatisfaction and potentially switching to some other firms.

Since quality is defined by a density function (Posner and Tapiero, 1988), true products characteristics are necessarily random (due to the production process, use and misuse of the product) quality claims truthfulness are inherently a postulate that remains to be tested and experienced. Thus, there is therefore, a probability that quality claims are not met. Quality claims that underestimate product characteristics might be “reliable”, namely, mostly true, but then they might not entice first time buyers, while overly optimistic quality claims might entice a backlash and negative quality information (which may have a substantial impact on a firm’s reputation). In this sense, the decision to set a quality claim is necessarily concurrent to the decision to “what quality to claim”. Such decisions are compounded by the fact that a consumer is also a consumer of services (such as warranties, product servicing, etc.) and firms profit not only from the revenues generated at the time of sale but also in derived revenues maintained as long as the customer remains a client of the firm. For example, the satisfied buyer of car insurance might also buy a home and life insurance. This example provides a preliminary approach to dealing with these issue by developing a default-prone risk model. Issues pertaining to repeat purchases versus first time buyers, how much and what to claim, etc., were considered in Tapiero 2005) using a queue like and optimal control model. Say that a quality claim is set numerically to some value K (for example, the life of a lamp, the mileage per gallon of a car, etc.). Performance however, is a function of numerous factors involving the usage conditions, the buyer use of the product, environmental factors etc. As a result, the performance-quality, \tilde{Q} is random defined at best by a density function which we denote by $f(\tilde{Q})$ (for example, lamps sold have an associated life time probability distribution). In this case, the probability of an “unsatisfied client, experiencing the product in fact, is also random and given by a probability which we define by: \tilde{p} where,

$$\tilde{p} = \begin{cases} 1 & \text{If } \tilde{Q} \geq K \\ 0 & \text{If } \tilde{Q} < K \end{cases}$$

As a result, the expected probability of an unsatisfied client and its variance are:

$$\hat{p} = \int_0^K f(x)dx = F(K) \quad \text{and} \quad \sigma_p^2 = \left(\int_0^K f(x)dx \right) \left(1 - \int_0^K f(x)dx \right) = F(K)[1 - F(K)]$$

For convenience assume that quality is defined in a range of [0,1] and therefore the expected quality and its variance are defined by:

$$\hat{Q} = \int_0^1 xf(x)dx, \quad \sigma_Q^2 = \int_0^1 (x - \hat{Q})^2 f(x)dx$$

While, the extent of dissatisfaction (non-quality) by a customer has a mean and variance defined in terms of the quality claim and the experienced quality, which we can calculate as follows:

$$\hat{L} = \int_0^K (K - x)f(x)dx \quad \text{and} \quad \sigma_L^2 = \int_0^K (K - x)^2 f(x)dx$$

For a firm, with D clients, the number of “recalls” n due to an unsatisfied customer is then (assuming

for simplicity that all recalls are statistically independent, which is clearly not the case), is then a Binomial distribution with parameters (D, \hat{p}) . Thus, the resulting distribution is a Lexian mixture with mean and variance given by:

$$E(n) = D\hat{p}, \quad \text{var}(n) = D\hat{p}(1 - \hat{p}) + D(D-1)\sigma_p^2$$

Note that in this case, the effects of the quality density function on the variance of quality claims increases at a quadratic function of the number of buyers. In this sense, “size” does matter in setting quality claims. If (again for simplicity, and to outline the basic financial approach to pricing the quality claim), we assume that a product is sold at a marginal profit π (the sale price less the production cost) and incur a per unit cost for each dissatisfied buyer, then, the net profit realized at say, time $t=1$, is $\tilde{P}_1 = D\pi - c\tilde{n}$. The expected net profit at this time and its variance are therefore:

$$E(\tilde{P}_1) = D\pi - cE(\tilde{n}) \quad \text{or} \quad E(\tilde{P}_1) = D\pi - cDF(K)$$

$$\text{var}(\tilde{P}_1) = c^2 \text{var}(\tilde{n}) \quad \text{or} \quad \text{var}(\tilde{P}_1) = c^2 D^2 F(K)(1 - F(K))$$

Let the utility of such a profit be $u(\cdot)$ while the certain equivalent at this time is defined by

$$Eu(\tilde{P}_1) = u(CE_1) \quad \text{or} \quad CE_1 = u^{-1}(Eu(\tilde{P}_1))$$

When default of products are dependent, subject to a common source of risk for example, then the effects of quality claims can be far greater (see Tapiero, 2009b for a development of default dependence). If we define a quadratic utility by $u(\tilde{P}_1) = \tilde{P}_1 - \rho(\tilde{P}_1 - E(\tilde{P}_1))^2$, then the expected utility is: $Eu(\tilde{P}_1) = E(\tilde{P}_1) - \rho \text{var}(\tilde{P}_1)$. Further and elementary analysis points out that for a risk averse firm, the index of risk aversion ρ is positive while the certain equivalent for neutral and an infinitely risk averse firms are given by $CE_1 = E(\tilde{P}_1)$, $CE_1 = E(\tilde{P}_1) - \sqrt{\text{var}(\tilde{P}_1)}$ respectively. In other words, for such firms, there is a value $\lambda \in [0, 1]$ such that:

$$CE_1 = E(\tilde{P}_1) - \lambda \sqrt{\text{var}(\tilde{P}_1)}, \quad \lambda \in [0, 1]$$

By the same token for a risk loving firm, we have $\lambda \in [-1, 0]$. As a result, we have: a certain equivalent:

$$CE_1 = E(\tilde{P}_1) - \lambda \sqrt{\text{var}(\tilde{P}_1)}, \quad \lambda \in [-1, 1]$$

Since the certain equivalent is a fixed quantity, at time $t=0$, when the price of such a planning quality and sales program is contemplated, we have a current price given by CE_0 , which is:

$$CE_0 = \frac{1}{1 + R_f} CE_1 \quad \text{or} \quad CE_0 = \frac{1}{1 + R_f} \left(E(\tilde{P}_1) - \lambda \sqrt{\text{var}(\tilde{P}_1)} \right)$$

In this sense, an optimal quality claim at the initial time $t=0$, is found by maximizing the current certain equivalent which we rewrite explicitly by:

$$\frac{CE_0}{D} = \frac{1}{1 + R_f} \left(\pi - c \left(F(K) + \lambda \sqrt{F(K)(1 - F(K))} \right) \right)$$

An optimal claim is found by setting $\frac{\partial CE_0}{\partial K} = 0$ which leads to:

$$\frac{\partial CE_0}{\partial K} = 0 \rightarrow 0 = f(K) + \lambda \frac{f(K)(1-F(K)) - F(K)(1-f(K))}{2\sqrt{F(K)(1-F(K))}} = 0$$

and therefore,

$$\lambda = \frac{2f(K)\sqrt{F(K)(1-F(K))}}{F(K) - f(K)}$$

As a result, the price of a product of quality claim K is given by:

$$CE_0 = \frac{1}{1+R_f} D \left(\pi - cF(K) - 2c \frac{f(K)(F(K)(1-F(K)))}{F(K) - f(K)} \right) > 0$$

In other words, the price “today” implies the claim and vice versa, the claim implies the price. The quality density function, reflecting the production technology and the controls of quality set in place are thus reflected in the distribution functions $f(K)$ and of course its parameters. In this case, the sell price per unit cost for an unsatisfied customer is necessarily given by:

$$\frac{\pi}{c} > F(K) \left[1 - 2 \frac{f(K)(1-F(K))}{F(K) - f(K)} \right] > 0$$

For example, say that the quality density function has the following probability distribution, $f(x) = (1-\alpha)x^{-\alpha}$, $x \in [0,1]$, then $F(x) = x^{1-\alpha}$ and therefore, $F(K) = K^{1-\alpha}$ as well as:

$$\lambda = \frac{2(1-\alpha)\sqrt{K^{1-\alpha}(1-K^{1-\alpha})}}{K - (1-\alpha)}$$

Further, the average quality is $E(x) = (1-\alpha)/(2-\alpha)$. For example, if the average quality equals 0.4, then $\alpha = 0.333$ and therefore,

$$\lambda = \frac{1.32\sqrt{K^{0.66}(1-K^{0.66})}}{K - 0.666}$$

As a result, a firm claiming a quality less than 0.666 is “risk loving” while one claiming more than 0.666 is risk averse. In other words, even claiming the average quality is likely to incur greater costs. This is an expected result as the more one claims, the greater the number of clients dissatisfaction. The price per unit produced is in this case given by:

$$\frac{CE_0}{D} = \frac{1}{1+R_f} \left(\pi - c \left(K^{0.66} + \frac{1.32(K^{0.66}(1-K^{0.66}))}{K - 0.666} \right) \right)$$

4. Conclusions

Risk and quality are converging naturally (Tapiero, 1997, 2007, 2009a, 2009b, Kogan and Tapiero, 2007). Combining both perspectives, in conjunction with an analysis of distribution characteristics and decision complexities, offers some opportunities for improved management of organizations, processes and financial resources. Additional applications of the models presented to the assessment of usability of web sites offering eCommerce services can be found in Kenett et al., 2009. Another area where quality and risks are combined is dealing with accident prevention and tracking of operational risks in financial institutions. For such an application involving text mining techniques and association

rules see Kenett and Salini, 2008. In general the convergence of quality and risk will help us move from numbers, to data, to information and knowledge (Kenett, 2008). To conduct this convergence we refer to the four quadrants proposed by Taleb (2008). In general, Taleb's Black Swan's thought provoking concepts are critical to stimulate the convergence. The quadrants give a systematic mapping of the problems at hand and how they are treated. Addressing the gap between models or so called "fitness landscapes" on which optimization is conducted, and reality requires special viewing abilities. Converging quality and risk perspectives provides such complementary views, thus generating new insights and higher information quality.

This topic is in its infancy and we believe more will follow on this track. The introspection carried out by economists and financial engineers, following the events of 2008/2009 has convinced many that new paradigms need to be investigated. Convergence of quality and risk is one such approach.

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