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Erasmus University Rotterdam
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Room H15-28
☎ 010 – 408 1314 / fax: 010 – 408 9136
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ABSTRACT

In this paper we describe a multicriteria framework for risk management that makes use of both concepts borrowed from multicriteria analysis and of concepts borrowed from modern financial economic theory. Over the years, this framework has proven its use in applications such as portfolio management, capital investment selection, financial planning and performance evaluation. The use of the presented framework is certainly not limited to financial decisions. Especially applications in which uncertainty and risk play an important role may benefit from the framework.

The framework is based on three pillars:

1. It makes use of all available information. At the same time, it does not make irrealistic assumptions with respect to the availability of information. So in our approach, decision makers are not squeezed out to provide information they do not possess. Actually, we do not torture them at all.
2. Borrowing from modern financial economic theory, the framework incorporates a rich toolbox for describing uncertainty and risk. It includes the multi-factor approach, contingent claims, game elements and combinations – depending on the situation at hand.
3. The framework integrates the above elements in a process- oriented approach towards financial decisions.

The present paper concentrates on the toolbox for describing uncertainty and risk.

A MULTICRITERIA FRAMEWORK FOR RISK ANALYSIS

Winfried Hallerbach & Jaap Spronk[1]

1. Introduction

Many of the theoretical developments in Multicriteria Decision Analysis took off in the seventies and eighties. In the meantime, the field has attracted many academic researchers from literally all over the world and from a great variety of disciplines. Also, many of the approaches proposed to tackle multicriteria decision problems have been and are being used in practice. Some approaches have even gained a rather wide acceptance in practice. One may wonder what is the reason for the enormous attention for and success of multicriteria decision analysis. At the same time one may also wonder why the use of multicriteria decision analysis in practice has not yet been much larger, where so many researchers are strongly convinced of its great potential and practical relevance.

Reasons for the attention for multicriteria decision analysis may be found in the dissatisfaction with more traditional decision support methodologies in which decision makers were pressed into iron harnasses of assumptions being hardly acceptable in many if not most real-life situations. Other reasons may be found in the cultural developments that originated around and during the seventies, by which many value systems were shaken and reshaped into more multifarious value systems.

The question why multicriteria decision analysis has not yet been used even more widely cannot be simply answered by stating that it takes time for new decision technologies to become accepted. Of course it takes time, but some methodologies are accepted very quickly while others are accepted only very slowly or even not accepted at all. We believe that many methodologies have difficulties in finding acceptance because they are still based on many too rigid assumptions with respect to the availability of data, the information processing capabilities of decision makers and with respect to the preferences and choice behaviour of decision makers. One notable example is the way multicriteria decision analysis deals with uncertainty and risk. Either uncertainty and risk are

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[1] Both Erasmus University Rotterdam, Rotterdam Institute of Business Economic Studies, and Tinbergen Institute Graduate School of Economics.

neglected all together or they are dealt with by making rigid distribution assumptions. In the first case, risk factors are sometimes introduced by decision makers through the definition of criteria that are somehow intended to control the risk inherent in the decision problem. In the second case, one often finds that it is simply assumed that a probability distribution is available which is then used as input for the multicriteria decision analysis. We believe that multicriteria decision analysis will gain much wider acceptance if it pays considerably more attention to uncertainty, risk analysis and risk management.

In this paper we describe a multicriteria framework for risk analysis that makes use of both concepts borrowed from multicriteria analysis and of concepts borrowed from modern financial economic theory. Over the years, this framework has proven its use in applications such as portfolio management, capital investment selection, financial planning and performance evaluation.[2] The use of the presented framework is certainly not limited to financial decisions. Especially applications in which uncertainty and risk play an important role may benefit from the framework. The framework is based on three pillars:

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2. Borrowing from modern financial economic theory, the framework incorporates a rich description of uncertainty and risk. It includes the multi-factor approach, contingent claims, game elements and combinations – depending on the situation at hand.
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The paper is organized as follows. Section 2 presents five snapshots of uncertainty and risks involved in problem solving. Section 3 concentrates on the modelling of uncertainty and risk given a particular decision context. Section 4 concludes the paper and outlines some directions for future research.

2. Five snapshots of uncertainty and risk in problem solving

In conventional micro-economic theory and in the 'traditional' decision methodologies that apparently have borrowed many of their assumptions from micro-economices, simplifying assumptions are made with respect to the

[2] For applications and further references, see Vermeulen, Spronk & Van Der Wijst [1996] and Spronk & Hallerbach [1997].

preferences of the decision maker and with respect to the representation of choice alternatives. Assuming that all necessary information is available, decision rules can be derived that are *normative* and *conditional* on the above two sets of assumptions, cf. Keynes [1891]. One of the charms of multicriteria decision analysis is that most of the time not too many rigid preference assumptions are being made but, as argued above, the uncertainty and risk aspects are often treated inadequately. For most decision makers, dealing with uncertainty and risk is an integral part of daily life. To illustrate this point, we will give five snapshots, including commentary, of problem solving and the associated uncertainties and risks. These snapshots relate to *(1)* problem awareness, *(2)* problem identification, *(3)* different ways of describing problems, *(4)* risks in modelling problems and *(5)* modelling uncertainty.

(1) Problem awareness means that one recognizes there *is* a problem to be solved. Problems can be of different nature. For instance, a potential labour strike is a threat whereas the possibility of a take-over of another firm may be a great opportunity. Systematical scanning and monitoring of one's activities may reduce the risk of not recognizing problems or recognizing problems too late (e.g. the intriguing Y2K problem that has surprised already many and will probably surprise many more at the dawn of the next century!).

(2) Even if one is aware that there are problems to be solved one has to decide which problem(s) is (or are) to be addressed and in which order. The apparent risk in this *problem identification stage* is addressing the wrong problem.

(3) There are many *different ways of describing problems.* As many philosophers and scientists from P.L. Ato to P.L. Yu [1990] have noted, the problem formulation depends on the person(s) who formulate the problem and on the language (defined in a broad sense) they speak. As such you do not describe 'the' problem but 'your projection of the problem against the wall'.

(4) Even if there is no doubt with respect to the way in which a particular problem can be described, there are still *many risks in modelling the problem.* Important choices have to be made regarding – among others:

-the identification of the decision maker(s)
-the problem horizon
-the static,comparatively static or dynamic nature of the problem
-the description of the preferences
-the description of the opportunities
-the description of the relationships between preferences and opportunities.

The choices one can make and the 'correctness' of these choices will depend on the quality of both the available set of information (e.g. are all data relevant, are there any biases?) and the body of knowledge of the decision maker and his/her helpers (e.g. what do we know for sure, is there anything ignored, do we suffer from illusions?). Fortunately, depending on one's learning potential, analytical skills and imagination people do learn. People learn to get a better view on an existing problem on the basis of new information, new insights and falsification of old insights. People do also learn in situations in which the problem setting is changing over time. In terms of the work of Yu [1990], the possibility to learn given a fixed problem setting can be summarized with the help of Figure 1.

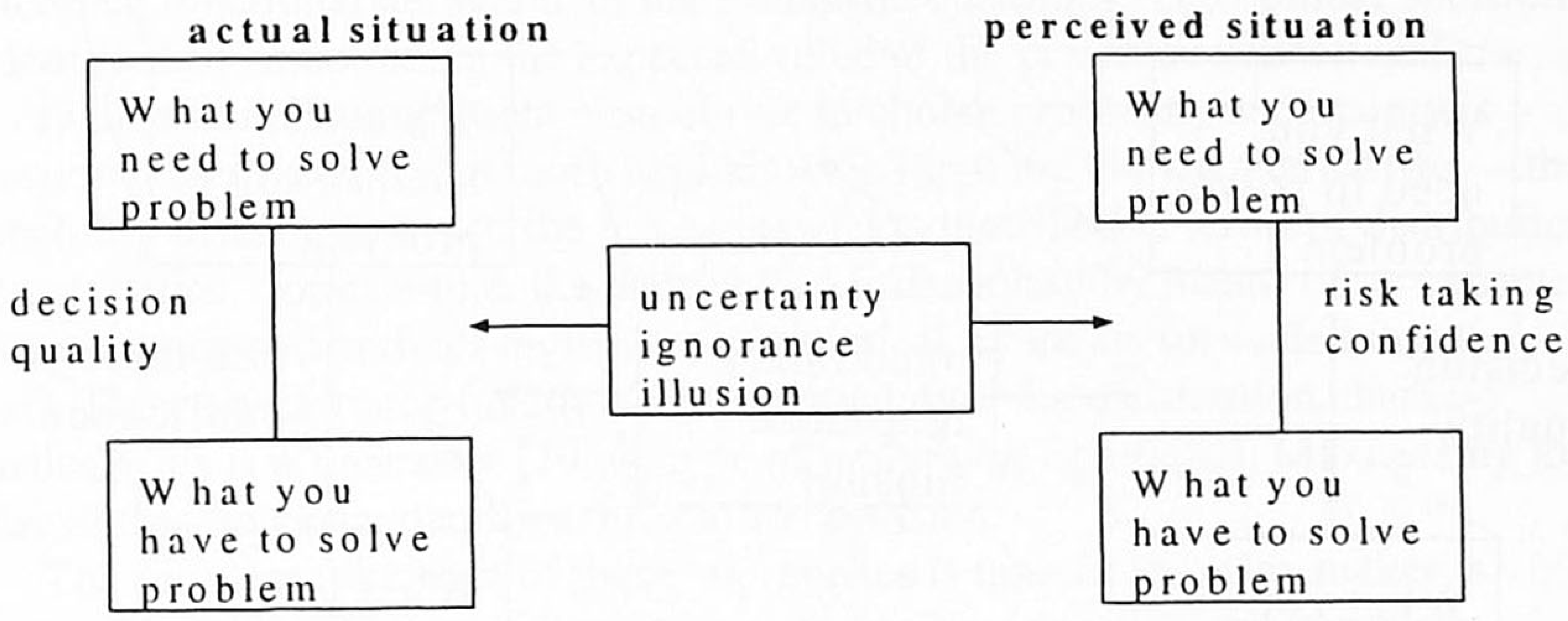

Figure 1: Uncertainty and learning in a fixed problem setting

On the left there is the (unobservable) set of 'what you need' and of 'what you have' to solve a problem. Obviously, the better the 'need' set is covered by the 'have' set, the better the decision quality. On the right are the same two sets, but now as perceived by the decision maker. In this case, the decision maker can make a 'calculated risk' and feel more or less confident about the decision made. Also, the decision maker can try to expand the perceived 'have' set by acquiring new information and by learning – thus getting a better coverage of the 'need' set. The bridge between the actual and the perceived situation is formed by intrinsic uncertainty, ignorance and illusion.

Figure 2 shows the same relationships for the case the problem setting is changing. A dynamic version of the comments to Figure 1 is easily given and thus left to the reader.

(5) The fifth snapshot concerns the *modelling of uncertainty and risk.* Conventional approaches normally assume that uncertainty can be caught in well-defined probability distributions that can be specified because of the implicit assumption of complete information. The above discussion already suggests that often in real-life problems, incompleteness of information is the rule rather than exception. Ignorance and illusions do exist, together with biases in estimation and flaws in data. The following section shows how to cope (or to live) with some of these problems.

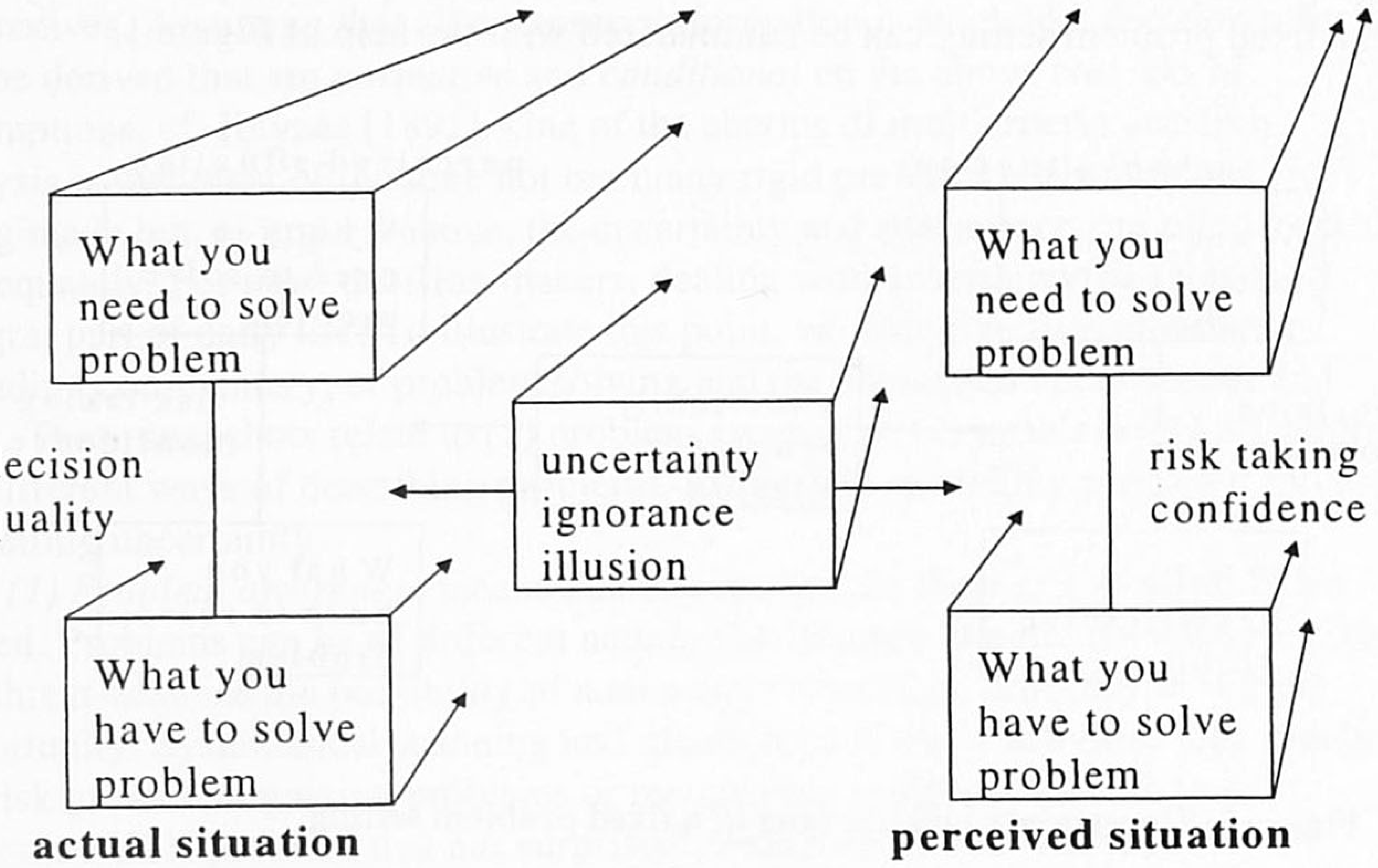

Figure 2: Uncertainty and learning in a changing problem setting

3. Describing uncertainty and risk in decision problems

After the uncertainty and risks involved in recognizing, identifying and describing decision problems, this section addresses the modelling of uncertainty and risk given a particular decision problem. Basically, there are two perspectives to this intrinsic risk: *ex-ante*, related to prospective choice problems, and *ex-post*, related to retrospective performance evaluation issues. For the time being, we'll ignore the latter and confine ourselves to the former.

In section 3.1 we first briefly summarize two conventional representations of risk and uncertainty in decision problems. In section 3.2, we then outline the key concepts of a competing way of representation, which leads to a prototypical classification of decision problems. Section 3.3 discusses these prototypical problems in more detail, making a first step from risk analysis towards risk management and incorporating some important insights from finance theory.

3.1 Conventional representations

In the conventional representation of decision making under uncertainty, all decision alternatives are given and fixed. The alternatives are first described in terms of their possible outcomes. Next, for each decision alternative, the decision maker must assess a probability distribution defined over the outcomes of the alternative. In this way, the decision problem is translated into one of choosing between alternative probability distributions defined over all possible outcomes. Uncertainty is incorporated by expressing the preference structure in terms of a preference functional defined over the stochastic outcomes. The optimal decision is identified by maximizing the expected value of the preference functional.

In an alternative representation of risk in choice problems, uncertainty is incorporated in a somewhat more explicit way. First, the choice alternatives – the probability distribution(s) of the outcomes – are described in terms of distribution characteristics. For example, the distribution is described by means of its expected value,variance and perhaps higher order statistical moments (provided that they exist). Then a preference functional is specified over the distribution characteristics. This is a Lancaster [1966]-type of preference functional. Maximizing the value of this function identifies the optimal decision.

The problem with both of these approaches is that the decision maker is assumed to have sufficient information as to be able to specify the complete probability distributions, either directly, or indirectly through specifying the distributions' moments. Furthermore, the decision maker is assumed to be able to specify the preference functional concerned. The latter assumption, or rather its high degree of irrealism, has given rise to the development of multicriteria decision analysis. Here, we address the first problem, the often irrealistic assumption of sufficient information to be able to specify probability distributions. Below, we present a competing approach, intended to support the modelling of uncertainty and risk in the case of partial information.

3.2 An alternative way of describing uncertainty and risk in decision problems

In decision problems under uncertainty and risk, *two questions* play a crucial role:

- where does the uncertainty stem from or, in other words, what are the sources of risk?
- when and how can this uncertainty be changed?

The answer to the first question leads to the decomposition of uncertainty. This involves attributing the inherent risk (the potential variability in the outcomes) to the variability in several underlying state variables or factors. We can thus view the outcomes as being *generated* by the factors. Conversely, the stochastic outcomes are *conditioned* on these factors. The degree in which fluctuations in the factors propagate into fluctuations in the outcomes can be measured by response coefficients. These sensitivity coefficients can then be interpreted as exposures to the underlying risk factors and together they constitute the multi-dimensional risk profile of a decision alternative.

The answer to the the second question leads to three prototypes of decision problems:

A. The decision maker makes and implements a final decision and waits for its outcome. This outcome will depend on the evolution of external factors, beyond the decision maker's control.

B. The decision maker makes and implements a decision and observes the evolution of external factors (which are still beyond the decision maker's control). However, depending on the value of these factors, the decision maker may make and implement additional decisions. For example, a decision maker may decide to produce some amount of 'a new and spectacular software package' and then, depending on the development of the market, he may decide to stop, decrease or increase production.

C. As in B, but the decision maker is not the sole player and thus has to take account of the potential impact of decisions made by others sometime in the future (where the other(s) are of course confronted with a similar type of decision problem). The interaction between the various players in the field gives rise to dynamic *game situations.*

Below, we will discuss each of these three prototype decision problems in somewhat more detail, paying attention to the situation that information is less than perfect. In prototype A problems the importance of multi-dimensional risk profiles is sketched. Prototype B problems involve the use of contingent claims whereas in prototype C problems game aspects are added.

3.3 Three prototypical decisions in the case of imperfect information

Multi-dimensional risk profiles in "prototype A" problems

The complexity of the decision process stems from assessing probability information regarding the outcomes (the "information problem") and from confronting this probability information with the preference structure of the decision maker (or incorporating it in some preference functional, the "criterion problem"). In general, the process of conditioning and decomposition greatly reduces the complexity of the decision process.[3] With respect to the information problem, decomposition reduces the complexity of risk judgments because it allows shifting attention from the uni-dimensional probability distribution of the outcomes to the exposures to the multi-farious underlying factors, summarized in

[3] The general idea of decomposition for the resolution or reduction of uncertainty can be traced to Simon [1962]. The process of conditioning described here is in the spirit of the stochastic hierarchies of Raiffa [1968].

the risk profile.[4] In this setting, the decision maker is relieved of the burden to explicitize the probability distribution of the outcomes. Moreover, it isn't even necessary that he or she has detailed information regarding the distributions of the factors. When a decision alternative shows a larger sensitivity (in absolute sense) to some factor j, it has a larger exposure to factor j risk, meaning that potential fluctuations in that factor propagate to a larger extent into potential fluctuations of the outcomes. So when two decision alternatives have the same risk profile except for the exposure to factor j, the alternative with the smaller exposure is less risky. This brings us to the criterion problem. Instead of the need to incorporate either the whole probability distribution of the outcomes or its relevant moments in the decision process, it suffices to express preferences with respect to the risk profile as summarized by the factor exposures. These sensitivity coefficients thus become the relevant risk attributes of the decision alternatives. Now, for example, again a Lancaster [1966]-type of preference functional can be specified, but now over the various risk exposures and other relevant attributes. An even less demanding alternative is to employ an interactive choice procedure. Asking the decision maker to evaluate the trade-offs between the risk attributes does not entail heroic preference assumptions.

A multidimensional view on risk allows multidimensional attitudes towards risk. A decision maker can show different degrees of aversion towards variability in the outcomes depending on the specific type of the underlying risk generating factor. Aside from the type of risk source, also the size of the exposure matters. A small exposure combined with a large factor variability can generate the same degree of risk as a large exposure combined with a small factor variability. However, the decision maker can face restrictions on risk exposures or possess smaller or larger buffers to absorb different types of risks. An example of the former is a restriction placed by a firm on the currency risk attached to its sales abroad; an example of the latter is the stock of input resources a firm holds in order to maintain production continuity.

Risk and variability are by no means synonymous. In general, there is a clear dichotomy between downside variability and upside variability. When a decision maker strives to maximize an alternative's outcome, downside risk can be separated from upside potential. When a decision maker instead strives to minimize the outcome, the asymmetry is reversed. This observation not only holds in general for the potential variability in the outcomes, but also more specifically for the potential fluctuations of the factors. Not only restrictions on risk exposures play a role, or the presence of buffers to absorb the unwanted part of variability, but also the availability of specific instruments that can be used to mitigate or eliminate the exposure to some part of factor variability. This leads us to the issue

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[4] In effect, combining the conditional distributions of the outcomes with respect to the factors with the marginal (joint) distributions of the factors yields the unconditional distribution of the outcomes. Ravinder, Kleinmuntz & Dyer [1988] analyze the measurement error that can be attributed to the use of decomposition when compared to direct assessment.

of risk management and the application of derivative instruments, as discussed below.

A multidimensional view on risk quite naturally allows for performing sensitivity analyses. Given the factor exposures, it can be analyzed how the outcomes are influenced by various changes of the factor values. Likewise, the decision maker can determine how the outcomes are influenced by hypothesized changes in the exposures to the factors. This implies a dynamic instead of a static approach to problem solving. The decision maker can *(i)* evaluate the different risk profiles that are generated by the set of available alternatives; by examining the trade-offs offered by the alternatives he can *(ii)* obtain new insights and shape his preferences in more detail, or *(iii)* realize that he needs more information on a specific part of the problem. Because of this interdependence between the characteristics of the choice alternatives and the decision maker's preferences, the aspect of *learning* in a complex decision situation gains importance. This leads us to sutuations where the decision maker may take additional decision, depending on the course of the environment.

The use of contingent claims in "prototype B" problems

It is important to distinguish between potential variability and risk, and also between *sources* of risk and *exposures* to risk. The former distinction is important because of the potential asymmetric nature of risk, whereas the latter follows directly from the principle of conditioning underlying a multi-factor representation. In a capital budgeting context, an investment project derives its present value from the future cash flows it generates. The project's cash flows –and hence its value– can be conditioned on factors describing its economic context, like commodity prices, exchange rates, interest rates and inflation. The tuplet of its exposures for these factors constitute the project's characterizing risk profile. This multi-dimensional representation enriches the project's description and enhances its evaluation. This applies even when information about the type and nature of risk sources or about the exposures is *incomplete*. By pasting as many pieces of the puzzle as possible together, one can obtain an impression of the weak and strong sides of the project, especially when comparing it to other competing projects.

When evaluating a portfolio of investment projects, also the *diversification effect* is relevant. Not the sum of the risks attached to the separate projects is relevant, but the risks attached to the sum of the projects. The lower the degree of dependence between the underlying risk factors, the greater the benefits reaped from the diversification effect. Aside from diversification, a firm may control risks by *matching* factor exposures. Combining a project with an exposure to factor j of +1 with a project with an exposure of –1 will in effect eliminate the exposure to factor j risk.

portfolio

When evaluating risk profiles of decision alternatives, not only the trade-off between the various risk exposures is relevant, but also the trade-off between risk on the one hand and value or return on the other. This *risk-return trade-off* implies that there is a reward for bearing risks. For example, lowering a project's risk exposures can at the same time decrease its value or profitability. A firm must then compare the risk-return trade-off offered by the portfolio of investment opportunities to the risk-return trade-off implied by its degree of risk aversion. So, generally speaking, there is a reward for risk offered by the decision alternatives, and there is premium for risk required by the decision maker – the subjective price of risk. To complicate things in a necessary way, there is in addition a reward for risk offered and required by the "outside world". When this so-called market price of risk exceeds the subjective price of risk, the firm clearly has a comparative advantage – i.e., compared to the outside world – in bearing the risk. The firm then has specific and valuable expertise in handling the risk in the decision context at hand . Selling the risk to third parties in the outside world implies paying a market compensation that is too high from the firm's point of view.

Above, we already mentioned the possibilities of diversification and matching in order to change risk profiles. But what opportunities does a firm have to sell risks to third parties? This question opens a whole toolbox of financial instruments, designed for hedging purposes. These instruments can be used in many other (multicriteria) decision problems. At this point, we like to stress the importance of derivative instruments or *"contingent claims"* to transfer risk exposures from parties that do not want or are not able to bear these risks, to parties who are better equipped to handle them. Option contracts, forward contracts, futures, and swaps are some examples of derivatives that allow a firm to hedge, i.e. to adjust individual risk exposures by shifting them to others.[5] Option contracts take a special position, since they work in an asymmetric way, like insurance contracts: they allow selling the downside risk of an exposure (by paying a market price) while maintaining its full upside potential. By chosing the right kind of contingent claims contract, risk exposures can be eliminated with surgical precision – provided the decision maker has sufficient knowledge of the nature of the contracts involved. With the increasing complexity of the available contracts, a detailed and sophisticated contingent claims analysis is a prerequisite to successful risk management.

Contingent claims analysis not only focuses on explicit options (i.e. the options that are traded on financial markets) but also on implicit options. The latter options are embedded in decision alternatives and manifest themselves as "flexibility". For example, during the life of an investment project the firm may expand the project when profitable or abandon it when it proves disappointing. A firm may even have the option to postpone the decision and start a project when and if market conditions prove favorable.[6]

The above discussion urges us to expand the description of decision alternatives. Of course, the exposures to the underlying sources of risks are still an

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[5] Smithson & Smith [1995] provide a good introduction to financial risk management and the use of derivatives for hedging.

[6] For an overview, see for example Brealey & Myers [1996].

essential part of a risk profile. To this, we have to add the aspects of flexibility, relating to the possibility to make decisions somewhen in the future depending on the evolution of the environment.

Contingent claims and games in "prototype C" problems

The decision maker is of course not the sole player in this environment. This implies that the potential impact of decisions taken by others sometime in the future must also be taken into account. The interaction between the various players in the field gives rise to *game situations*. For example, suppose we have two competitors, firm A and firm B. Firm A expects B to enter the market and is trying to understand B's likely pricing strategy. Firm A can then construct a payoff matrix, summarizing the payoffs (sales or net profit, e.g.) under various pricing strategies. Firms A and B have perverse incentives to lower prices: maintaining prices at the current level while the competitor cuts prices will lower the payoff. Like in the prisoner's dilemma, both firms are inclined to cut prices, thus both lowering their payoff. As a result, we can imagine that each firm then will separately try to compete on other factors, like product features, service levels or advertising. An analysis of this pricing game can only be made when the firm has information about costs to enter and exit the market, about demand functions, about revenue, cost structures etc. So the decision process has various dynamic aspects, stemming on the one hand from flexibility in the own decision context and on the other hand from the impact of other parties' decisions on this decision context. Because of these dynamic aspects, the role of learning – from your own decisions and from others – cannot be underestimated.

4. Summary and conclusions

We described a multicriteria framework for risk management that makes use of concepts borrowed from both multicriteria analysis and modern financial economic theory. Over the years, this framework has proven its use in applications such as portfolio management, capital investment selection, financial planning and performance evaluation. However, its scope is much broader: especially applications in which uncertainty and risk play an important role may benefit from the framework.

The framework is based on three pillars. First, it makes use of all available information. At the same time, it does not make irrealistic assumptions with respect to the availability of information. So in our approach, decision makers are not expected to provide information they do not possess. Second, borrowing from modern financial economic theory, the framework incorporates a rich description of uncertainty and risk. It includes the multi-factor approach, contingent claims, game elements and combinations – depending on the situation at hand. Finally, the framework integrates the above elements in a process-oriented approach towards financial decisions.

In the present paper we concentrated on the modelling of uncertainty and risk. Starting from five snapshots of problem solving and the associated uncertainties and risks (problem awareness and identification, problem description and modelling, and modelling uncertainty), we focused on how uncertainty in a decision context can be changed. Depending on the flexibility to take additional decisions when new information arrives and the possibility to interact with third parties, we distinguish between three prototypical decisions. We discussed each of these decisions and provided some examples.

A number of the ideas and concepts set out above (e.g. the concept of multifactor models and that of contingent claims), were borrowed from finance. During the last decade, finance has embraced risk analysis and risk management very strongly, both in theory and practice. We believe that many of these ideas and concepts can also be applied fruitfully in all other areas of (multicriteria) decision making under uncertainty. We encourage the reader to get acquainted with some of the standard references in risk management that have emerged in the financial discipline (Smithson & Smith [1995], e.g.) so that these insights can fertilize efforts in other areas.

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