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THE IRR, NPV AND PAYBACK PERIOD AND THEIR RELATIVE PERFORMANCE IN COMMON CAPITIAL BUDGETING DECISION PROCEDURES FOR DEALING WITH RISK

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ABSTRACT

The relative performance of six capital budgeting decision procedures for dealing with risk was studied using Monte Carlo computer simulation of long sequences of capital rationing decisions involving risk. Five of the decision procedures included either subjective or objective risk assessment and used common measures of worth: Net Present Value, Internal Rate of Return, and Payback Period. The sixth decision procedure was random selection. Also investigated were (1) the effects of errors in risk assessment and (2) the effectiveness of the decision strategy to prefer opportunities with short-term capital recovery periods to reduce the exposure to risk of the capital invested.

INTRODUCTION

Risk, no matter how slight, is an element of virtually every capital budgeting decision. Numerous decision procedures have been proposed in the literature and reported in surveys of practitioners for dealing with risk. However, the relative performance of these decision procedures in attaining the decision maker's financial objective while also dealing with risk effectively in long sequences of capital rationing decisions is not clear. There is a need, therefore, for studies to evaluate the relative, long-term performance of common capital budgeting decision procedures used in practice and proposed in the literature for dealing with risk.

This paper reports the results of one such study [1]. The study used Monte Carlo computer simulation of long sequences of capital rationing decisions to evaluate the relative effects on the capital growth rate and risk of ruin of simulated firms each using one of six capital budgeting decision procedures for dealing with risk. The six decision procedures were:

1) $RNPV/r_a$, Rank on Net Present Value (NPV) with risk-adjusted discount rate r_a,
2) $RIRR/r_a$, Rank on Internal Rate of Return (IRR) with risk-adjusted discount rate r_a,
3) $ROPP/n_a$, Rank on Payback Period with risk-adjusted payback period n_a,
4) $RNPV/n_a$, Rank on NPV with risk-free discount rate r as the primary criterion, and Payback Period with risk-adjusted payback period n_a as the secondary criterion,
5) $RNPV/\beta$, Rank on (expected value) NPV with risk-free discount rate r as the primary criterion, and profitability risk restriction $Pr[NPV < 0 \leq \beta\ ]$ as the secondary criterion, and
6) Random Selection.

The first five of these decision procedures use common measures of worth, IRR, NPV, or Payback Period, as the measure of economic merit, and similarly, they also exhibit some common approaches for dealing with risk. Four of them, $RIRR/r_a$, $RNPV/r_a$, $ROPP/n_a$, and $RNPV/n_a$, assess risk subjectively by using either a risk-adjusted discount rate or a risk-adjusted cutoff payback period for dealing with risky investment opportunities, and the fifth, $RNPV/\beta$, uses an opportunity's NPV probability distribution to assess an opportunity's risk more objectively. The sixth decision procedure, Random Selection, was included in the study as a benchmark.

Also common to the first five decision procedures is that it is possible for a decision maker to err in assessment of an opportunity's risk. That is, in the case of the subjective risk assessment techniques in the first four decision procedures, a decision maker's judgment could be incorrect, or in the case of the more objective risk assessment technique in the fifth decision procedure, a decision maker's estimation of the governing probability distributions and related parameters could be inaccurate. Thus, a decision maker may misperceive an opportunity as risky and perhaps reach a decision that is different than would have been reached had the decision maker perceived the opportunity's risk correctly. Similarly, a decision maker could misperceive an opportunity as not risky and fail to account for risk at all. Misperception in risk assessment was also one of the issues studied.

Therefore, this study sought, partly, to obtain insights into the relative performance of these particular decision procedures but, mostly, to gain a better understanding of the effectiveness of the philosophies underlying these decision procedures for the treatment of risk in long sequences of capital rationing decisions involving risk. Related research has yielded valuable insights for decision procedures that do not consider risk [15,17,20,21,22,24,25,35]. This study serves to add that body of knowledge as further information about and understanding of the performance of different approaches for dealing with risk in capital budgeting decision making.

In the remainder of this paper some of the fundamental philosophies and principal decision techniques for dealing with risk that are used in practice and discussed in the literature are described first. Five capital budgeting decision procedures that reflect these philosophies and techniques are then presented; the sixth decision procedure presented is random selection. The essential elements of the simulation model used and the model's measures of performance are discussed subsequently, and the results of five simulation experiments are then presented.

ACCOUNTING FOR RISK

Capital budgeting practices have been documented in various surveys [4,5,11,26,29,32] and summarized collectively in other publications [6,27]. With respect to the perception of risk in practice, Gurnani [6] observed:

> *"Risk in the capital budgeting context includes financial risk associated with leverage, business risk associated with the type of activity engaged in, risk of technological change, obsolescence and risk due to errors in estimation of the parameters entering into analysis... Because of the reward system in industry, executives in general are risk adverse, and they favor measures that can be translated into explicitly measurable goals. Risk is perceived by the majority of them as either the probability of not achieving a given target return or the degree of downside. When proposed projects involve a small portion of the budget, risk is merely the prospect of not meeting the target. However, for large investment proposals, a possibility of insolvency exists and hence the emphasis is on downside risk."*

Risk assessment in practice is predominently subjective. Schall, *et al.* [29] found that 4% of firms surveyed gave no consideration to risk, 60% assessed risk subjectively, and 36% used some quantitative analysis, mostly sensitivity analysis or Monte Carlo computer simulation of an opportunity's cash flows. Other methods reported to account for risk were to adjust (increase) the discount rate, 19%, decrease the maximum acceptable payback period, 14%, use certainty equivalence, 3%, and employ utility theory, 3%. Gitman and Forrester [5] found that 43% of the firms they surveyed increased the discount rate, 26% used expected values of cash flows, and 13% decreased the maximum acceptable payback period. Kim and Farragher [11] reported that Payback Period was used as a secondary measure by 39% of their 200 respondents from large industrial corporations. Pike [26] found in 100 large industrial firms in the United Kingdom that "naive appraisal methods" and "spreadsheet techniques" such as Payback Period, shortening the maximum acceptable payback period, increasing the discount rate for risk, and sensitivity analysis still enjoy wide support.

The approaches suggested in the literature for dealing with risk in capital budgeting decision making range from very simple to extremely complex. Some authors suggest simple adjustments to the measure of worth values or the decision rules [30], others suggest developing probability distributions of measures of worth or cash flows for risky opportunities [8,9], while others employ mathematical programming techniques such as stochastic linear programming, linear programming under uncertainty, chance constrained programming, and goal programming [2,10,28].

Despite some theoretical deficiencies, and the existence of more sophisticated approaches, the simpler approaches are still the ones commonly used in practice to deal with risk. Thus, this study investigated five decision procedures that reflect the fundamental philosophies and techniques discussed used in practice for dealing with risk in capital budgeting decision making. They use common measures of (economic) worth and well known mechanisms to account for risk. A sixth, random selection, served as a benchmark. We precede the description of these decision procedures with some terms and definitions.

TERMINOLOGY

Risk results from uncertainty. It is perhaps for this reason that the terms risk and uncertainty are often used interchangeably. Indeed, variance, which is a measure of dispersion (uncertainty), is commonly used as a measure of risk. However, variance is not a measure of risk and, in this paper, the terms uncertainty and risk will not be used interchangeably. *Uncertainty* exists when the outcome of a random event is not known *a priori*, regardless of whether the probability distribution that governs it is known or not. *Risk* is the probability of an undesirable outcome, a definition which is consistent with its use in industry [6] and in common language [33]. A firm can thus be exposed to any number of risks, each defined by its undesirable outcome. For example, the term *risk of (economic) loss* could be used to describe the probability of not achieving a specified target return, and the *risk of ruin* could be used to describe the probability of insolvency. Thus, as used in this paper, uncertainty *per se* conveys nothing about the undesirability (or desirability) of the possible outcomes of a random event, whereas risk does.

Ranking decision procedures are common in practice. A *ranking decision procedure* can be described formally as follows. A schedule of opportunities is ranked in decreasing order of attractiveness according to the value of a specified measure of worth. Opportunities whose measure of worth value does not meet an acceptable value according to a specified decision rule are rejected. The remaining opportunities are accepted one at a time beginning from the top of the list and continuing down the list until either the budget or the list is exhausted. Among the weaknesses of ranking decision procedures are that they do not necessarily consider increments of investment (i.e., an incremental analysis) nor do they necessarily optimize the investment of the budget in the sense of maximizing future wealth. Both of these weaknesses would be avoided with a mathematical programming decision procedure using a measure of worth based on the financial objective of maximizing the decision maker's future wealth.

A *risk assessment decision procedure* is used to evaluate an opportunity's risk according to a specified measure of risk. One approach would be to classify opportunities into risk classes according to the subjective judgment of the decision maker and then subject each opportunity to a more or less stringent hurdle of economic acceptability according to its risk class [16]. A more sophisticated decision procedure would evaluate the risk of each opportunity according to a probabilistic measure and reject those whose risk (probability) exceeds a specified acceptable probability. A major issue in either case is the importance of assessing the risk of an opportunity accurately.

Of the six decision procedures studied, five can be characterized as ranking, risk assessment decision procedures, four of which use subjective risk assessment techniques and one uses a more objective risk assessment technique. The sixth, random selection, of course, uses neither a measure of economic merit nor risk assessment. In this paper, *a subjective assessment* of an opportunity's risk is one in which the decision maker uses deterministic measures that are adjusted, as deemed appropriate, based on the decision maker's intuition, judgment, experience, etc. Sensitivity analysis is an example of a widely used subjective risk assessment technique. An *objective assessment* of an opportunity's risk is one in which the decision maker uses probabilistic measures based on estimates of the appropriate governing probability distributions and related parameters (e.g., means, variances). This is not to imply that one approach is necessarily better or preferred to the other, but rather to note their differences. One relies principally on a decision maker's intuition and judgment about an opportunity's uncertainty and risk in the absence of objective measures of that uncertainty and risk, and the other does not.

Presumably, the reason decision makers perform risk assessments, whether subjective or objective, is to assess how the acceptance of an individual opportunity may affect the firm's long-term capital growth rate and risk of ruin, i.e., its long-term viability. The decision procedures studied address the risk of (economic) loss of an individual opportunity failing to meet some desired level of profitability, and not, at least not directly, how the opportunity individually may affect the risk of ruin of the firm. They are representative of the more common techniques used in practice in which a decision maker's consideration of an opportunity's potential affect on the firm's risk of ruin is based primarily on an evaluation of its risk of loss. The six decision procedures studied are as follows.

RANK ON NPV WITH RISK-ADJUSTED DISCOUNT RATE, $RNPV/r_a$

For $RNPV/r_a$, opportunities are ranked according to their (expected value) NPV where each opportunity's NPV is computed using a specified risk-adjusted discount rate, r_a, for the risk class, $a = 1, 2, 3, \ldots$, to which an opportunity is judged to belong. Opportunities judged not risky are classified as risk-free and their NPVs are computed using a specified risk-free discount rate, r. It is assumed that $r_a \geq r$ for all risk classes. The decision rule associated with the measure of worth NPV is that opportunities with a positive valued NPV are considered acceptable.

The philosophy for dealing with risk underlying $RNPV/r_a$ is that by using expected values of net cash flows to calculate an opportunity's NPV, some of the variability in the net cash flows can be captured. Since probability distributions for the net cash flows are typically not determined for this decision procedure, the net cash flow values can be described as the decision maker's perception (estimation) of the expected values. Opportunities deemed risky have their attractiveness reduced relative to other opportunities deemed safer by adding a so-called risk premium to the discount rate. It should be noted, however, that the use of a higher discount rate can affect not only the ranking of risky opportunities relative to other safer opportunities *but also the ranking among risky opportunities.*

RANK ON IRR WITH RISK-ADJUSTED DISCOUNT RATE, $RIRR/r_a$

For $RIRR/r_a$, opportunities are ranked according to their IRR. Similar to $RNPV/r_a$, expected value cash flows (or the decision maker's perception of them) are used to compute the IRR for each opportunity and a risk-adjusted discount rate is then used to evaluate an opportunity's acceptability according to the risk class to which it was judged to belong. Opportunities deemed not risky are judged using the risk-free discount rate, r. The decision rule associated with the measure of worth IRR is that an investment opportunity is considered acceptable if its IRR exceeds the specified cutoff discount rate. A more complete discussion of the IRR, its proper use as a measure of worth, and the problems of multiple internal rates of return and mixed investment-borrowings can be found in [13,19]. This paper does not delve into these issues.

The philosophy for dealing with risk underlying $RIRR/r_a$ is similar to $RNPV/r_a$. *However, the use of a higher discount rate for risky opportunities* *does not affect the ranking of any opportunity relative to the other opportunities, risky or not, and possibly affects only an opportunity's acceptability.* Further, while ranking on IRR generally violates the principle of decisions based on differences, studies have shown nonetheless that it performs quite well [15,20,25].

RANK ON PAYBACK PERIOD WITH RISK-ADJUSTED CUTOFF PAYBACK PERIOD, $ROPP/n_a$

For $ROPP/n_a$, opportunities are ranked according to their Payback Period. The measure of worth, Payback Period, is the smallest number of periods in which an investment opportunity recovers its investment together with interest at a specified rate. It is computed using either the risk-free discount rate, r, or a discount rate equal to zero. The latter is often called "undiscounted" payback period. A risk-adjusted payback period, n_a, is specified for each risk class of opportunities. The decision rule associated with the measure of worth Payback Period is that an opportunity is considered acceptable if its payback period is less than n_a. We will refer to n_a hereafter as the cutoff payback period.

The philosophy for dealing with risk underlying $ROPP/n_a$ is that recovering one's investment sooner lessens the exposure to risk of the capital invested. By ignoring "distant" cash flows, it is advocated that $ROPP/n_a$ recognizes that risk (actually uncertainty) increases with time [34]. It is not clear, however, that recovering the investment sooner reduces the risk since the returns are reinvested in other opportunities and thus capital is, in essence, always at risk. In reality, $ROPP/n_a$ neither addresses uncertainty nor risk, but there are those who nonetheless extoll its virtues in dealing with uncertainty and risk. On the other hand, $ROPP/n_a$ does tend to select opportunities that return funds sooner thus making incremental funds available for further investment. However, its proponents have presented no evidence that receiving funds sooner is better for the firm. The decision strategy of choosing opportunities with a short-term capital recovery was investigated in one of the experiments in this study.

Since Payback Period measures the time for recovery of an investment and not profitability *per se*, its contribution toward maximizing a firm's wealth is doubtful. Nonetheless, it should do as well as or better than a random selection decision procedure that uses no measure of worth at all.

RANK ON NPV WITH SECONDARY MEASURE PAYBACK PERIOD, $RNPV/n_a$

Payback Period also enjoys wide use as a secondary measure [11][26]. $RNPV/n_a$ used NPV as the primary measure of economic merit and Payback Period as a secondary measure to deal with risk. Specifically, the decision procedure $RNPV$, computed with a risk-free discount rate, is used to identify an acceptable set of opportunities. From this set, opportunities are then selected that also meet a specified cutoff payback period, n_a. The underlying philosophy is to use NPV to identify the economically meritorious opportunities and then to screen out those deemed too risky as evidenced by their longer payback periods.

RANK ON NPV WITH RISK RESTRICTION ON NPV, *RNPV/β*

RNPV/β first ranks opportunities according to their expected value NPV, using a risk-free discount rate, and those with non-positive NPVs are discarded. It then screens out additional opportunties that do not meet the risk restriction of the probability of an undesirable NPV. A typical value for the upper limit on undesirable NPVs could be NPV = 0. This was the value used in our experiments. Thus, the risk restriction was $\Pr[\, NPV < 0 \leq \beta \,]$.

The underlying philosophy for this decision procedure is that by selecting opportunities that have only a small risk of loss (of not meeting a "target return" [6]), the risk of ruin to the firm can be reduced. More elaborate risk restrictions could also be formulated for the distributions that describe the net cash flows of the individual opportunities. In that case, only opportunities with acceptably low probabilities of having undesirable net cash flows would be selected. Risk restrictions on the net cash flows would represent a more restrictive approach for dealing with risk. Indeed, risk restrictions on net cash flows can be shown in certain circumstances to be a special case of a risk restriction on NPV. Regardless, adding either (or both) of these probability restrictions to RNPV acts only as a screen and does not alter the relative ranking of the opportunities.

RANDOM SELECTION

For random selection, opportunities are selected randomly without regard to either their profitability or risk. It requires no estimation of any parameters except for the opportunities' first costs. The decision maker is restricted from knowingly selecting opportunities that exceed the budget at the decision time. This decision procedure was included in the study as a benchmark by which to compare the more 'logical' decision procedures described above.

Logical decision procedures that use reliable information should perform better than random selection, but it is also expected that as errors in estimation of that information reduce its reliability, the performance of the logical decision procedures would approach that of random selection [15,20,22]. In cases of either extremely biased or misleading information, it is possible that some logical decision procedures could perform worse than random selection, as will be shown in the experiments performed.

A METHODOLOGY FOR EVALUATING DECISION PROCEDURES

Computer simulation in capital budgeting decision making is not new. For investigations requiring results from long sequences of realistic capital budgeting decisions in a timely, economical, and scientific manner, the only practical avenue is Monte Carlo computer simulation. It allows studies under controlled conditions at an affordable cost and with the freedom to define fairly complicated situations. It, of course, poses its own problems, such as appropriate model development, design of meaningful experiments, and defining measures of performance.

Early uses studied capital budgeting under uncertainty involving complete information [7,8,31]. Thuesen and Oakford [23,24] pioneered the use of computer simulation to investigate situations involving long sequences of capital rationing decisions under certainty and incomplete information. Subsequent researchers extended this approach to study a number of capital budgeting issues leading to the development of a model known as DecSim (a contraction of Decision Simulator) [3,17,21,25,35]. Risk was not considered in these studies since they either assumed certain cash flows or provided unlimited short-term credit to alleviate ruin. Lohmann and Oakford [15] extended DecSim in their studies to examine capital budgeting debt policies and risk. The study reported here developed a model called DURSIM (a contraction for Decisions Under Risk Simulator) and it can be viewed as an extension of DecSim.

The following is a brief description of the methodolgy used to study the relative performance of capital budgeting decision procedures for dealing with risk [1]. It highlights the fundamental elements of DURSIM so as to facilitate understanding and interpretation of the results of the experiments.

SIMULATING LONG SEQUENCES OF DECISIONS UNDER RISK

It is assumed a decision maker faces a long sequence of periodic capital rationing decisions involving uncertainty and incomplete information - *uncertainty* in that the cash flows that describe long-term investment opportunities available at the decision time are uncertain (random variables), and *incomplete information* in that the decision maker knows only the opportunities available currently but does not know (but expects) opportunities to become available at subsequent decision times. The sequence of decisions is assumed to have begun long ago, and, barring ruin, will continue into the indefinite future. This situation is most representative of an established firm that coordinates its capital rationing decisions with its annual budget review, although this model is applicable more broadly including such decision environments as personal portfolio management.

At each decision time, the decision maker is presented with a budget and a schedule of long-term investment opportunities. The long-term investment opportunities represent mostly investments in the firm's business. Each long-term investment opportunity in the schedule presented is summarized by its net cash flows. The decision maker selects a subset of opportunities from the schedule according to the budget and a specified decision procedure. Long-term investment opportunities are either accepted or rejected in their entirety and those selected cannot later be divested. Portions of the budget not invested in long-term investment opportunities, if any, are invested for one period in short-term investments (e.g., market investments) until the next decision time one period later. The budget available at a given decision time includes the returns to be received at that decision time from both long-term investments made previously as well as short-term investments, if any, made at the preceding decision time. In this study, borrowing was not allowed. Based on related research [15], it was believed that the additional modeling complications to allow borrowing would not yield significantly different insights.

The sequence of investment decisions continues until either a predetermined number of decisions is completed or the firm suffers ruin. The firm suffers 'ruin' if the budget at the current decision time is negative. In reality, firms would likely seek either short-term or long-term debt, or both, or other financial resources to cover the shortage [14]. Since the decision procedures studied are intended to help a decision maker avoid such circumstances, a definition of ruin was chosen so as to observe how effectively these decision procedures avoided placing the decision maker in such financial straits. At the completion of the simulation of a sequence of decisions, the vector of budget amounts available for future periods and the risk (probability) of ruin were used to describe the results of the firm's decisions and the performance of the decision procedure used.

MEASURES OF PERFORMANCE

A number of measures of performance could be used to evaluate the results of sequences of capital rationing decisions and each has its tradeoffs [1,12,17,23]. All of them, however, are based on the output budget vectors. A budget (cash flow) vector, whose first value occurs one period after the last decision in the sequence, is comprised of the future returns from investments selected from decisions prior to and including the last decision in the sequence. This vector, in essence, is the future value of the firm that the decision maker seeks to maximize as a consequence of the sequence of decisions.

Given identical input, two different simulation experiments could be compared in theory by comparing their output budget vectors. Such comparisons in practice would be difficult unless one budget vector dominated the other [15,20,24]. Consequently, a surrogate measure was used. For each simulation, an average input budget vector and an average output budget vector was computed using the input and output budget vectors from each replication of a sequence of decisions that did not result in ruin. These average budget vectors were then used to compute the 'average' capital growth rate of the firm, g_f, which was the IRR of the cash flow series formed by using the average input budget vector as the investment and the average output budget vector as the return.

Another output from the simulation is the risk of ruin of the firm, which can also be measured in many different ways. For this study the risk of ruin of a firm, p_f, was defined as the relative frequency (probability) with which replications of a sequence of decisions resulted in ruin (on or before the specified termination time for the sequence).

Thus, for each simulation of a long sequence of capital rationing decisions involving risk, two scalar measures of performance were obtained, $\{g_f, p_f\}$. Judgment is required in the tradeoffs between values of g_f and p_f in comparing the results of simulation experiments. If g_f is higher and p_f lower for one simulated firm than another, then presumably one firm did better relative to the other. To know whether either or both firms did well overall, however, requires subjective assessment of the values of g_f and p_f. Quantifying these tradeoffs in the experiments performed was not a major concern since the intention of the study was not to prove the superiority of one decision procedure over another but rather to observe their performance relative to one another under different situations.

GENERATION OF LONG-TERM INVESTMENT OPPORTUNITIES

Applying a specified decision procedure to schedules of long-term investment opportunities, recording the selections, and accounting for the resulting cash flow consequences are relatively straightforward bookkeeping processes. However, the process to generate long-term investment opportunities is a more central and critical element of the simulation and it needs to be described substantively.

Very little has been published on the long-term investment opportunities generation process of firms except for Viafore's study involving several large firms [32]. Even here, however, the results were inconclusive due to incomplete and inaccurate company records. Thus, data about the long-term investment opportunities generation process of firms are largely unavailable and unknown. Nonetheless, it seems reasonable to view long-term investment opportunities as the product of a stable random generation process.

One can envision two types of uncertainty associated with cash flows. One is uncertainty about cash flow outcomes given the governing probability distributions are estimated accurately and the other is uncertainty about the estimates of the governing probability distributions. In an environment of certainty, the cash flow forecasts used to make decisions are identical to the cash flows to be realized if the opportunity is selected. Under uncertainty, the cash flows to be realized cannot be known *a priori* - whether the cash flow distributions are known accurately or not. If a decision maker estimates the cash flow distributions accurately, then both the expected value cash flows and risks can be calculated accurately. If the decision maker errs in estimating the distributions, then the expected values and risks calculated by the decison maker will likely be in error and possibly affect the decision. The errors in estimation will not, of course, affect the cash flows eventually realized if the opportunity is selected. Related studies have shown that as the error in estimation of *cash flows* increases the long-term financial effectiveness of logical decision procedures approach that of random selection [15,21,22]. The decision procedures in those studies, however, did not include consideration of risk. Thus, this study focused on errors in *risk assessment* and its effects on the long-term survival of the firm.

The generation of cash flows for each long-term investment opportunity and the effects of errors in risk assessment were modeled as follows. An expected value version of the net cash flows of a long-term investment opportunity would be generated from specified (input) distributions which allowed variation (randomness) in the first cost, life, cash flow pattern of the returns, and IRR. In the case where the decision maker used $RNPV/\beta$, the probability of undesirable NPVs would be computed for each opportunity. When an opportunity was selected, another version of net cash flows was generated from the input distributions to represent the returns to be realized. The decision maker, of course, would learn about these values only over time as the returns were received and used to compose the budget at each decision time. Thus, the decision maker would make decisions based on the version representing the expected value net cash flows, and then receive over time the version representing the realized net cash flows from the opportunities selected.

Generation of a long-term investment opportunity also involved generation of its inherent uncertainty and risk classification. In practice, long-term investment opportunities can be envisioned that span a broad range of uncertainty and risk from none (or virtually none) to extremely speculative. This study classified long-term investment opportunities into only two classes: 'less risky,' henceforth referred to as 'safer,' and 'more risky,' henceforth referred to as 'risky.' This classification permitted understanding without undue calculation. *Nonetheless, it is important to remember that both classes involved uncertainty and risk -- one less, the other more.*

The effects of errors in risk assessment were modeled as part of the global characteristics used to simulate the generation of long-term investment opportunities under capital rationing. These characteristics included: the degree of capital rationing (the total cost of the opportunities relative to the budget), the distribution of IRRs of the long-term investment opportunities, and the relative riskiness of the long-term investment opportunities. These characteristics can be described in terms of a firm's *investment opportunities function*, as shown in Figure 1. It shows the fraction of the budget at each decision time, f, that could be invested in investment opportunities to grow at a given IRR or higher. The sloping portion of the curve represents long-term investment opportunities, and an infinite supply of short-term (market) investment opportunities were asumed available at an IRR of i. (A concave investment opportunities function is more representative of practice whereas we used the linear function shown to facilitate the calculations [32]. The shape of the investment opportunities function used here is irrelevant to the explanations of the results of our work.)

The value m is the IRR of the marginal long-term investment opportunity where the last increment of investment in long-term investment opportunities with an IRR greater than or equal to m would absorb all of the budget. It also represents the rate at which the (incremental) funds released by the decision about the current schedule of investment opportunities would be reinvested in the future [18]. The expected value IRRs of long-term investment opportunities were generated by random sampling from the investment opportunities function shown.

Both safer and risky long-term investment opportunities are represented in the investment opportunities function in Figure 1. The opportunities in each risk class can also be represented by two separate investment opportunities functions, one for safer opportunites and one for risky opportunities, as shown in Figure 2. Thus, Figure 1 is the combination of the two functions in Figure 2. In Figure 2, the risky investment opportunities function has been reversed to slope downward from right to left and superimposed over the safer investment opportunities function. Thus, if the fraction of the budget invested in safer long-term investment opportunities was, say, $f_s = 0.50$, then the fraction of the budget remaining available for investment in risky long-term investment opportunities would be $f_r = 0.50$. Of course, $f_s + f_r = 1.0$.

Since an interest of this study was the *effects* on the firm's capital growth rate and risk of ruin due to a decision maker's errors in risk assessment of individual opportunities, and not the manner by which a decision maker makes such errors, the model reflects the effect on the decision maker's selections and not necessarily the process by which such errors may occur in practice. Thus, the model reflected the notion that because of the decision maker's errors in estimation of cash flows, cash flow distributions, or intuition, a decision maker could misperceive a long-term investment opportunity's riskiness and either select it when it should have been rejected or vice versa. In fact, DURSIM can handle a wide range of misperceptions of risk. A decision maker could be modeled who either correctly perceived the risks of all opportunities, or misperceived all risky opportunities (thus they would be perceived as safer), or misperceived all safer

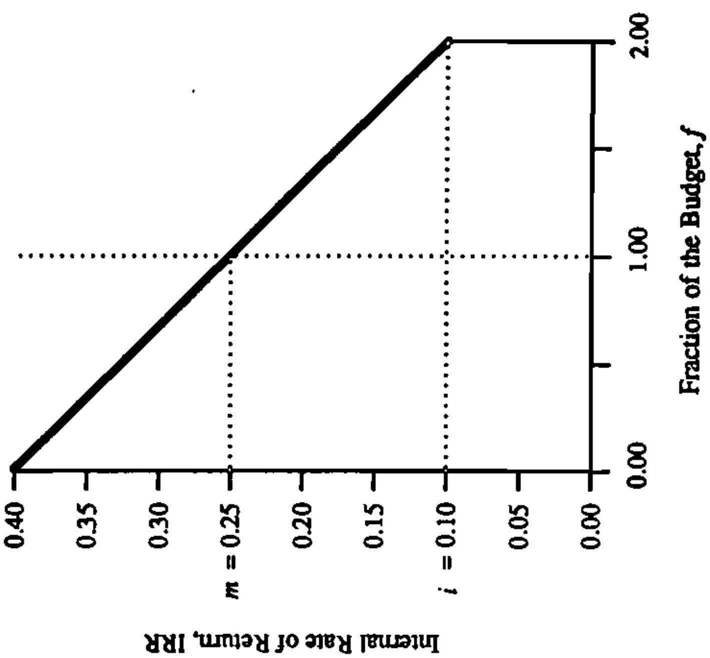


FIGURE 1. Investment Opportunities Function.

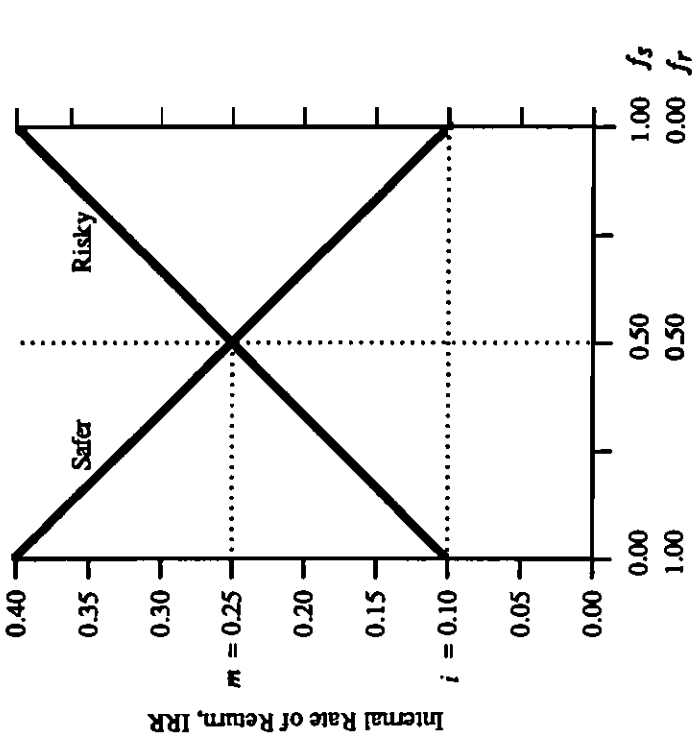


FIGURE 2. Safer and Risky Investment Opportunities Functions.

opportunities (thus they would be perceived as risky), or misperceived all opportunities (thus safer would be perceived as risky, and vice versa), or misperceived some fraction of safer opportunities and some fraction of risky opportunities (thus some would be perceived correctly and others not).

For $RNPV/r_a$, $RIRR/r_a$, $ROPP/n_a$, and $RNPV/n_a$, the effect of a misperception of a long-term investment opportunity's riskiness would be to subject the opportunity to a cutoff hurdle for the wrong risk class. For the risk class identified as safer, the cutoff hurdles were either the risk-free discount rate r (which was either the marginal growth rate, m, or the short-term investment rate, i, depending on the experiment), or an infinite cutoff payback period (in effect, the cutoff payback period was not restrictive and long-term investment opportunities judged safer were selected until either the budget or the schedule of opportunities was exhausted). For the risk class identified as risky, the hurdles were either a higher value of r_a or a lesser value of n_a.

For the decision procedure $RNPV/\beta$, the effect of errors in risk assessment were modeled as follows. In applying the decision procedure $RNPV/\beta$, the investment selection process was adjusted randomly according to the degree of error in risk assessment under study. For example, to study the effect of a decision maker who misperceives the risk of 50% of the risky long-term investment opportunities and none of the safer long-term investment opportunities generated at each decision time, half of the risky long-term investment opportunities available at each decision time would be randomly 'marked' (coded) to have their risk misperceived. Thus, some otherwise unacceptable risky long-term investment opportunities with positive expected value NPVs might be selected (budget permitting), some acceptable risky ones would be rejected, and still others with non-positive expected value NPVs would be rejected regardless of the misperceived risk.

FIVE SIMULATION EXPERIMENTS

Five simulation experiments were performed to observe the performance of: 1) $RIRR/r_a$ and $RNPV/r_a$, 2) $ROPP/n_a$, 3) $RNPV/n_a$, 4) $RNPV/\beta$, and 5) the risk avoidance strategy of choosing opportunities which promise short-term capital recovery. In most experiments, errors in risk assessment were studied in addition to investigation of the effects of other parameters. Four categories of errors in risk assessment were studied: 1) the risks of all long-term investment opportunities were perceived correctly, 2) the risks of all risky opportunities were misperceived and thus all opportunities were perceived as safer long-term investment opportunities, 3) the risks of all safer long-term investment opportunities were misperceived and thus all opportunities were perceived as risky, and 4) the risks of all long-term investment opportunities were misperceived and thus risky ones were perceived as safer and safer ones as risky. Misperceiving the risks of some fraction of the long-term investment opportunities was studied and these experiments produced results that are 'bounded' by the four cases above. Hence, these experiments are not presented.

Each experiment involved 100 replications of at most a sequence of 15 decisions. Thus, the total number of decisions for each experiment could be no less than 100, which would occur if the entity suffered ruin after the first decision of each replication, and no more than 1,500, which would occur if the entity did not suffer ruin for any decision.

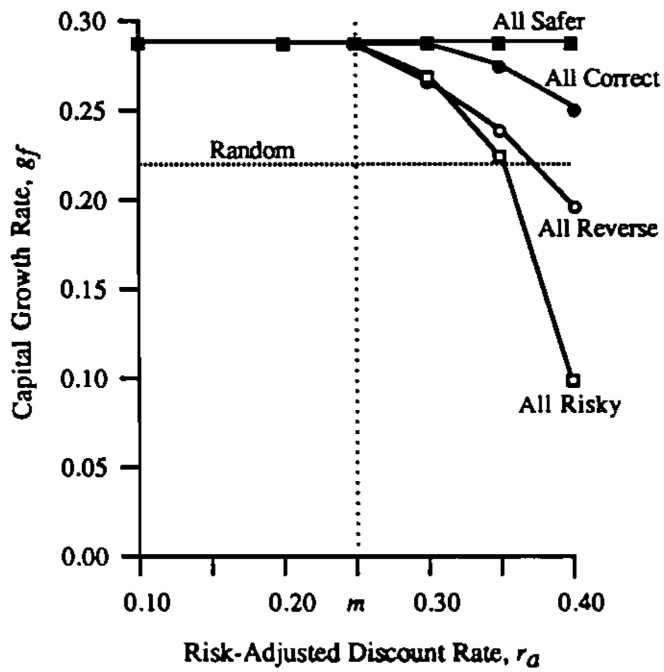
A comparison and evaluation of specific data points produced by one decision procedure with the data points produced by another decision procedure proved difficult in some cases because the values of g_f and p_f required subjective judgment of the tradeoffs between (typically) a higher g_f or a lower p_f, or there was not a one-to-one correspondance with some of the parameters that defined the decision procedures compared, for example, there is no basis to equate values of r_a and β in the decision procedures $RNPV/r_a$ and $RNPV/\beta$, or one decision procedure sought to attain a financial objective different than the others, for example, $ROPP/n_a$. Nonetheless, some useful general comparisons could be made and insights gained.

EXPERIMENT 1: THE PERFORMANCE OF $RIRR/r_a$ AND $RNPV/r_a$

The results of two sets of simulations involving $RIRR/r_a$ and $RNPV/r_a$ are shown in Figures 3 (a) and (b). The risk-free discount rate was the short-term investment interest rate $r = i = 0.10$, and the risk-adjusted discount rate was varied between 0.10 and 0.40. The results for both decision procedures were very similar and, therefore, the results for both will be discussed simultaneously. The results are also consistent with related research [15, 20, 24, 25].

In general, the decision procedures performed about equally well and were more insensitive for values of $r_a < m$ than for values of $r_a > m$. Except for the higher risk-adjusted discount rates, the capital growth rates using $RIRR/r_a$ and $RNPV/r_a$ were significantly higher than the firm using random selection but their risks of ruin were nearly equal to that of random selection. In general, $RIRR/r_a$ produced slightly higher capital growth rates than $RNPV/r_a$ but it also produced somewhat higher risks of ruin.

When the decision maker misperceived risky long-term investment opportunities as safer, thus treating all long-term investment opportunities as safer ("All Safer" in Figures 3 (a) and (b)), the values of g_f and p_f plot as horizontal lines displaying their independence of r_a. The capital growth rates were at or near the maximum value but the risks of ruin were also nearly equal to that of random selection (which is to be expected). In the opposite situation where the decision maker misperceived the safer long-term investment opportunities and



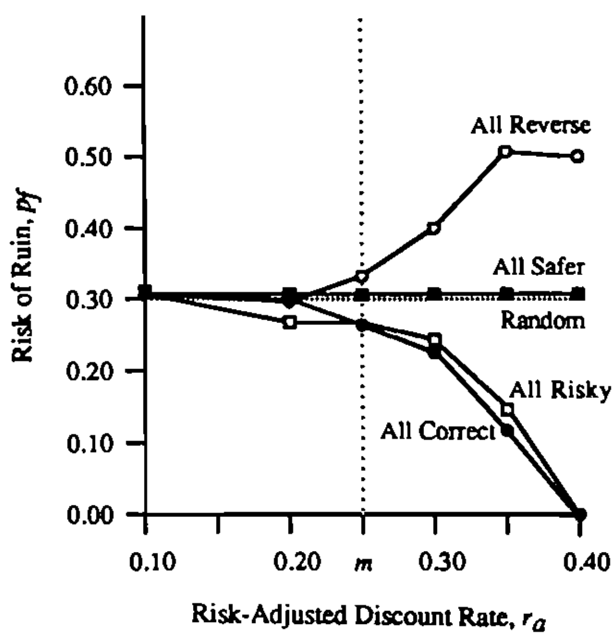


FIGURE 3 (a). Performance of $RIRR/r_a$.

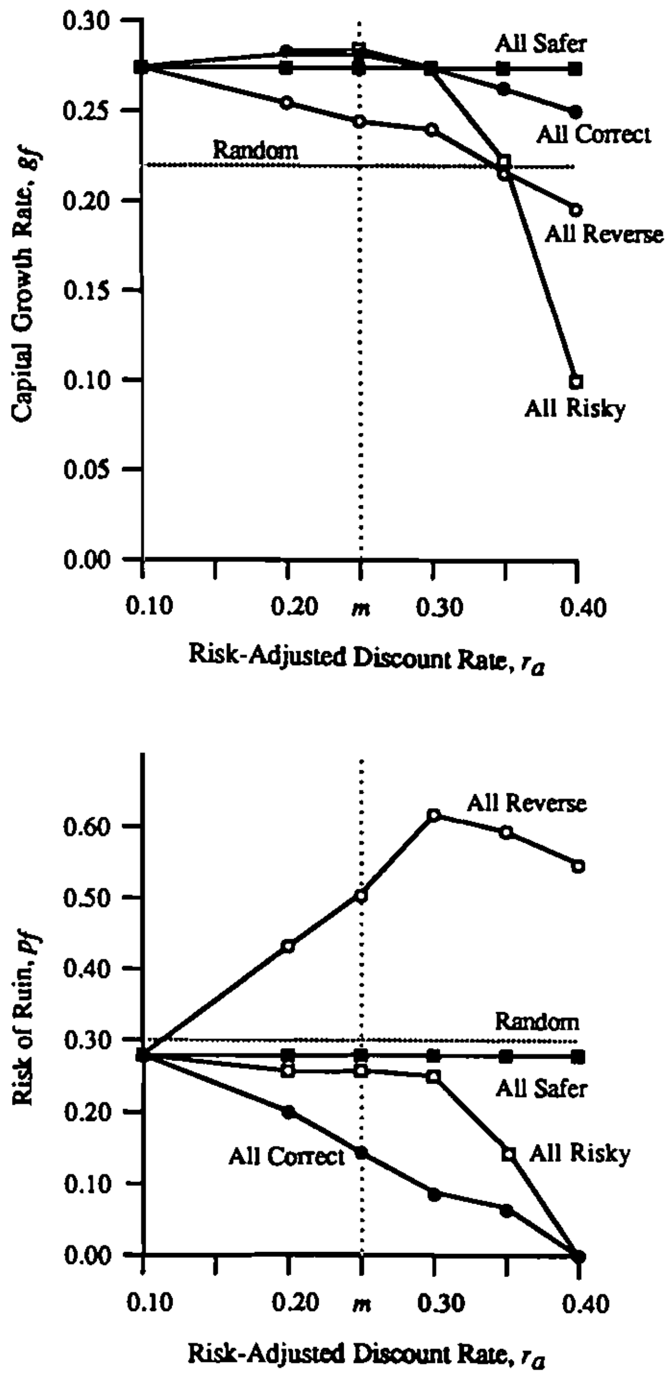


FIGURE 3 (b). Performance of $RNPV/r_a$.

treated every long-term investment opportunity as risky ("All Risky" in Figures 3 (a) and (b)), the capital growth rates were maximized when the risk-adjusted discount rate was equal to $m = 0.25$ (where, as shown in Figure 2, equal investment in long-term investments from both functions would absorb all the budget).

The relative insensitivity of g_f and p_f to $RIRR/ra$ for values of $r_a < m = 0.25$ for most risk misperceptions, and somewhat less so for $RNPV/r_a$, was because the budget, on the average, was exhausted before all of the acceptable long-term investment opportunities were selected. Thus, the budget tended to be invested in approximately equal amounts of safer and risky long-term investments. However, when $r_a > 0.25$ and for all risk misperceptions except when all opportunities were perceived safer, funds were diverted to either risky long-term investment opportunities from the safer ones ("All Reverse") because the risky ones were misperceived as acceptable or short-term investments ("All Correct", "All Risky") because all long-term investment opportunities viewed acceptable in both risk classes had been selected before the budget was exhausted.

It is clear from Figures 3 (a) and (b) that accuracy in risk assessment is important to derive the benefit of a high g_f and a low p_f. With a few exceptions, the capital growth rates were as good or better and the risks of ruin less or no worse for the situation where all opportunities were classified correctly than for the other three situations involving risk misperceptions. For the extreme case of reverse perception, the risk of ruin was dramatically worse than random selection. The benefits of risk reduction in $RIRR/r_a$ and $RNPV/r_a$, thus, are due largely to diverting funds from risky investments to either safer long-term investments or market investments to the extent the decision maker does a reasonable job of risk classification.

Similar experiments were conducted using $r = m = 0.25$ as the risk-free discount rate for long-term investment opportunities perceived safer. The results and observations were comparable to those above. The principal difference was that, in general, more funds were diverted to short-term investments as the risk-adjusted discount rate was increased since safer long-term investments with IRRs between $i = 0.10$ and $m = 0.25$ were now unattractive. The effect was to generally lower most of the values of g_f and p_f.

EXPERIMENT 2: THE PERFORMANCE OF $ROPP/n_a$

Figures 4 (a) and (b) show the performance of $ROPP/n_a$ for a range of cutoff payback periods between 3.5 and 0.75 for risky long-term investment opportunities. Figure 4 (a) shows the results when the risk-free discount rate used to compute the Payback Period was $r = i = 0.10$, and Figure 4 (b) shows the results when $r = m = 0.25$ was used. The cutoff payback period for long-term investment opportunities perceived safer was 5.0. This value was chosen because it

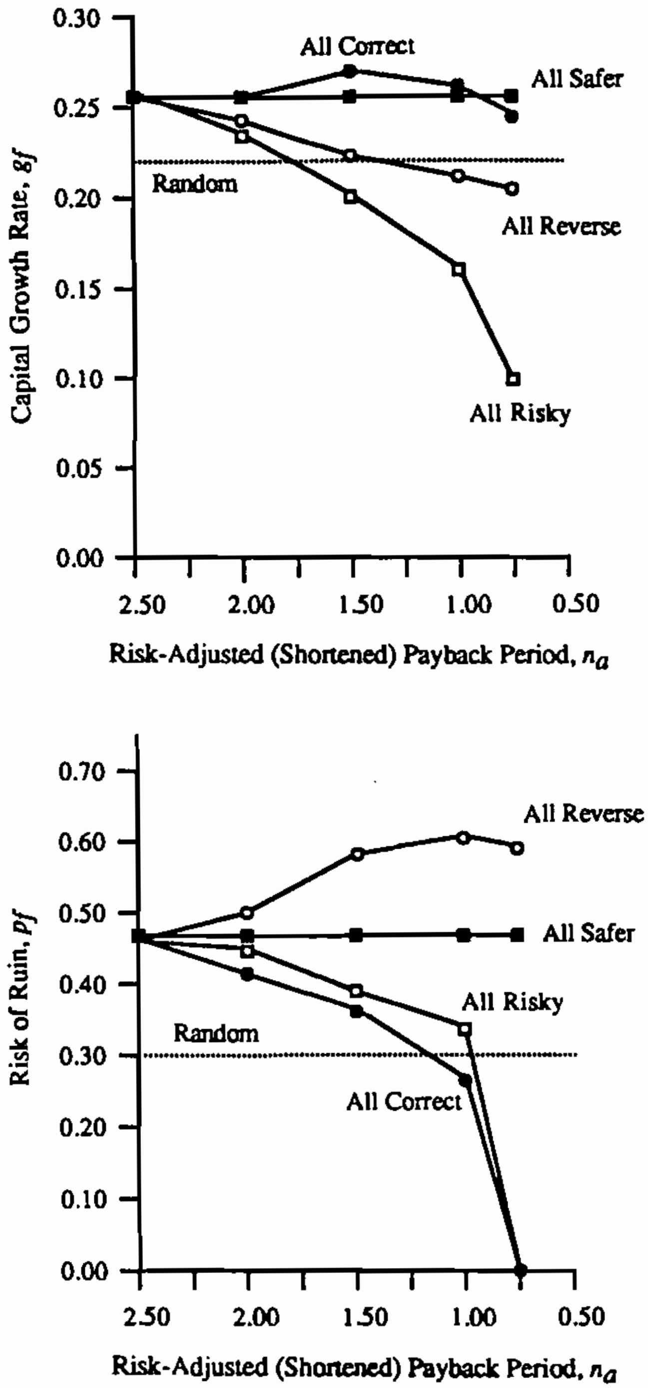


FIGURE 4 (a). Performance of $ROPP/n_a$
with Risk-Free Discount Rate $r = 0.10$.

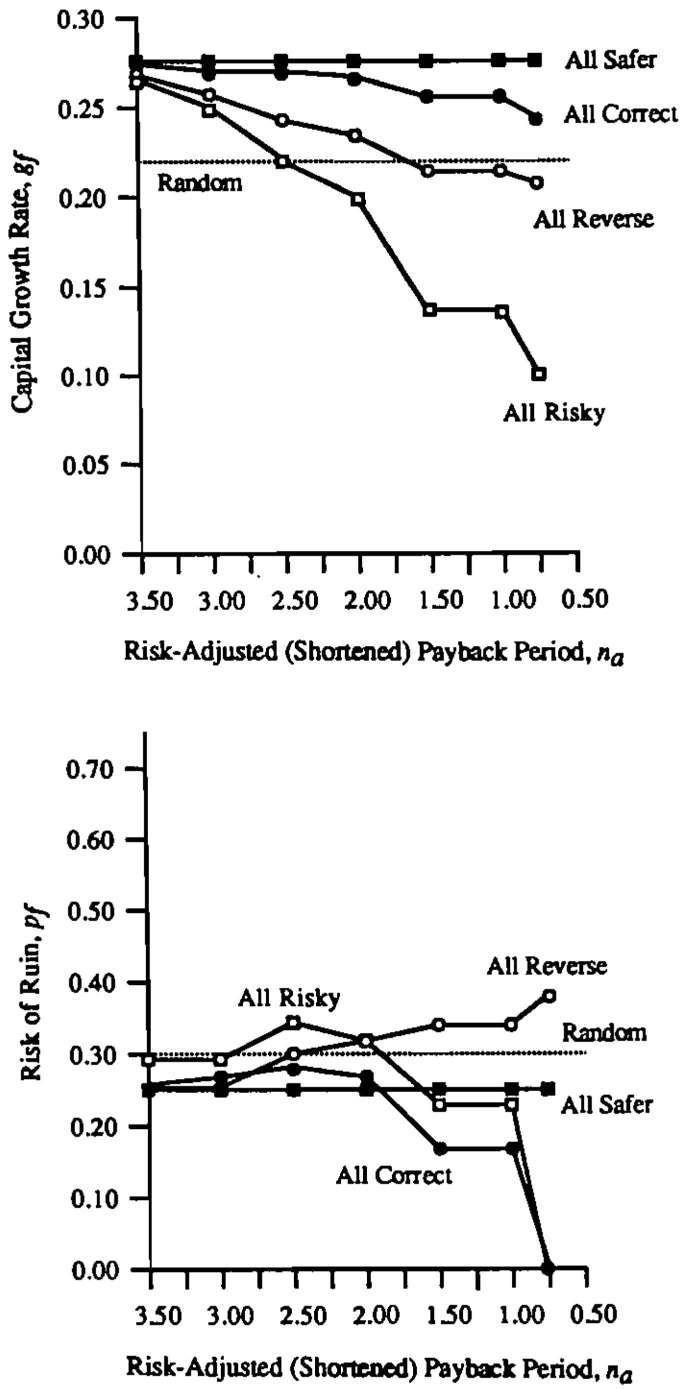


FIGURE 4 (b). Performance of $ROPP/n_a$ with Risk-Free Discount Rate $r = 0.25$.

guaranteed that no long-term investment opportunity perceived safer would be rejected for failure to satisfy this hurdle since all the long-term in vestment opportunities generated in these simulation experiments had a payback within 5 periods.

In examining Figures 4 (a) and (b), it is important to recognize that the discount rate used had a significant effect on the payback period computed. A long-term investment opportunity discounted at a higher discount rate yields a longer payback period. The maximum finite payback period of an opportunity is equal to the number of periods to the last cash flow, which occurs when the discount rate used is equal to the opportunity's IRR. Thus, the payback periods for opportunities with IRRs less than the discount rate used would be undefined since these opportunities would never pay back. In this study, such opportunities were assigned an infinite payback period. Hence, for a finite cutoff payback period, n_a, any risky long-term investment opportunity with an IRR less than the discount rate used was rejected. Consequently, for a given discount rate, the $ROPP/n_a$ decision procedure would reject at least a subset of long-term investment opportunities that would also be rejected had $RNPV/r_a$ and $RIRR/r_a$ been used. Thus, the application of $ROPP/n_a$, in a limited sense, is an implicit application of $RNPV/r_a$ and $RIRR/r_a$.

Note in Figure 4 (a) when the decision maker perceives all long-term investment opportunities as safer (that is, only the risky ones are misperceived) g_f and p_f plot as horizontal lines, thus exhibiting their independence of the cutoff payback period, n_a. In this case, the decision maker selected long-term investments by ROPP until the budget was exhausted. The capital growth rate was higher than random selection, but the risk of ruin was also considerably higher. By comparison with Figure 3 for the same situation, the capital growth rates for $RNPV/r_a$ and $RIRR/r_a$ were higher (both relative to random selection and to $ROPP/n_a$,) and the risks of ruin were lower. Since $ROPP/n_a$, is not designed to address maximization of future wealth, such comparisons of the capital growth rates involving $ROPP/n_a$, are not particularly meaningful. However, Payback Period is advocated as effective for dealing with risk and it is particularly interesting to note that a comparison of the risks of ruin suggests that selecting long-term investments on the basis of ROPP until the budget is exhausted may be worse than doing so on the basis of RNPV and RIRR, and even random selection.

The reduction in the risks of ruin accomplished by $ROPP/n_a$, for lesser values of n_a when the decision maker either perceived the risks of all the long-term investment opportunities correctly or perceived all long-term investment opportunities as risky was achieved simply by reducing the fraction of the budget invested in risky long-term investment opportunities and investing the funds either in safer long-term investment opportunities ("All Correct") or in short-term investments ("All Risky"). It is noteworthy that the risks of ruin were higher than random selection for almost all values of n_a. The exception occured when the risks of all long-term investment opportunities were perceived correctly and n_a was so reduced that virtually all of the budget was invested in either safer long-term investments or short-term investments.

As observed with $RIRR/r_a$ and $RNPV/r_a$, reverse perception resulted in the worst exposure to the risk of ruin.

Similar observations can be made from Figure 4 (b). The most notable effect from raising the risk-free discount rate from $r = i = 0.10$ to $r = m = 0.25$ to compute the Payback Period was the impact on the risks of ruin. For values of $r > 0.10$, the performance of $ROPP/n_a$ improved (g_f was higher and p_f was lower) because the budget was more fully invested in the better long-term investment opportunities whose IRR > 0.25 (because of the implicit application of the decision procedures $RNPV/r_a$ or $RIRR/r_a$ discussed above). In these simulation experiments, only about half of the long-term investment opportunities were acceptable according to $ROPP/n_a$. Hence, for the shorter values of n_a, the rank ordering of long-term investment opportunities according to Payback Period was often irrelevant because frequently all the acceptable opportunities were accepted. The results here are similar to $RNPV/r_a$ when $r_a = 0.25$ and all the long-term investment opportunities are perceived as risky. Thus, $ROPP/n_a$ when $r_a = 0.25$ drew mostly upon the inherent capability of $RNPV/r_a$ (or $RIRR/n_a$) since the rank ordering of the values of Payback Period did not materially effect the selections.

For shortened values of n_a, the improvement in p_f for the situations where all long-term investment opportunities were perceived either correctly or risky was due merely to diverting funds from long-term investment opportunities that failed to meet the cutoff payback period to either safer long-term investments or short-term investments since all acceptable opportunities (satisfying the cutoff payback period) were accepted and ranking was irrelevant.

It is interesting to note by comparing the curves in Figure 3 (a) and (b) with the curves in Figure 4 (a) that, in general, $RIRR/r_a$ and $RNPV/r_a$ performed better (higher g_f, lower p_f) than $ROPP/n_a$. A point-to-point comparison, however, is not possible since there is no basis to match particular values of r_a to particular values of na except, of course, for the situation where all long-term investment opportunities are perceived as safer and the values of r_a and n_a are irrelevant.

It appears that the benefits of $ROPP/n_a$ arise mostly from the implicit application of the hurdle to reject long-term investment opportunities with non-positive NPVs. In all cases, the benefits in reducing the risk of ruin by shortening the cutoff payback period were derived by simply reducing the fraction of the budget invested in risky opportunities to safer investments. As observed in Experiment 1, it is important to assess the riskiness of opportunities accurately.

EXPERIMENT 3: THE PERFORMANCE OF $RNPV/n_a$

Figure 5 illustrates the performance of Payback Period as a secondary measure when used with RNPV as the primary criterion. For this experiment, the risks of all long-term investment opportunities were perceived correctly. Figure 5 shows the effects of variation in n_a as well as r. Variation in the risk-free discount rate was included to observe the effect of such variation in combination with variation in n_a. The capital growth rates decreased with both shorter cutoff payback periods and/or higher discount rates. Reducing the cutoff payback period, of course, results in rejection of some risky long-term investments with otherwise acceptable NPVs. For lower values of r, where the total cost of long-term investment opportunities exceeded the budget, funds that would have otherwise been invested in long-term investment opportunities had they not been screened out by Payback Period were diverted to other long-term investment opportunities with a lower NPV and an acceptable Payback Period. However, for higher values of r, where the total cost of acceptable long-term investment opportunities was less than the budget, the funds diverted went instead to short-term investments.

Figure 5 illustrates a general trend of a decreasing risk of ruin (and corresponding decrease in the capital growth rate) as funds were diverted to either less economical long-term investments or short-term investments with increasing discount rate; however, a less consistent trend occurs with decreasing cutoff payback period. While the capital growth rate decreased noticeably with increased cutoff payback period, the risk of ruin changed less dramatically and less consistently (for $r = 0.10$ it increases, for $r = 0.35$ it decreases, and for $r = 0.$ 25 it does some of both). Figure 5 generally suggests that the use of Payback Period as a secondary measure has a marginal effect on controlling the risk of ruin but it can have a significant detrimental effect on the capital growth rate.

EXPERIMENT 4: THE PERFORMANCE OF $RNPV/\beta$

Figure 6 shows the results of the performance of *RNPV/ß* for values of $\beta =$ 0.0 and 0.10, and risk-free discount rates between 0.20 and 0.40. It is to be remembered that for $RNPV/\beta$ only the risk-free discount rate is used to compute the NPV for all long-term investment opportunities, both safer and risky. Futher, recall for $RNPV/\beta$ that an error in risk assessment means that the decision maker erred in estimating an opportunity's cash flow distributions to such a degree that a risky long-term investment opportunity whose (true) risk is

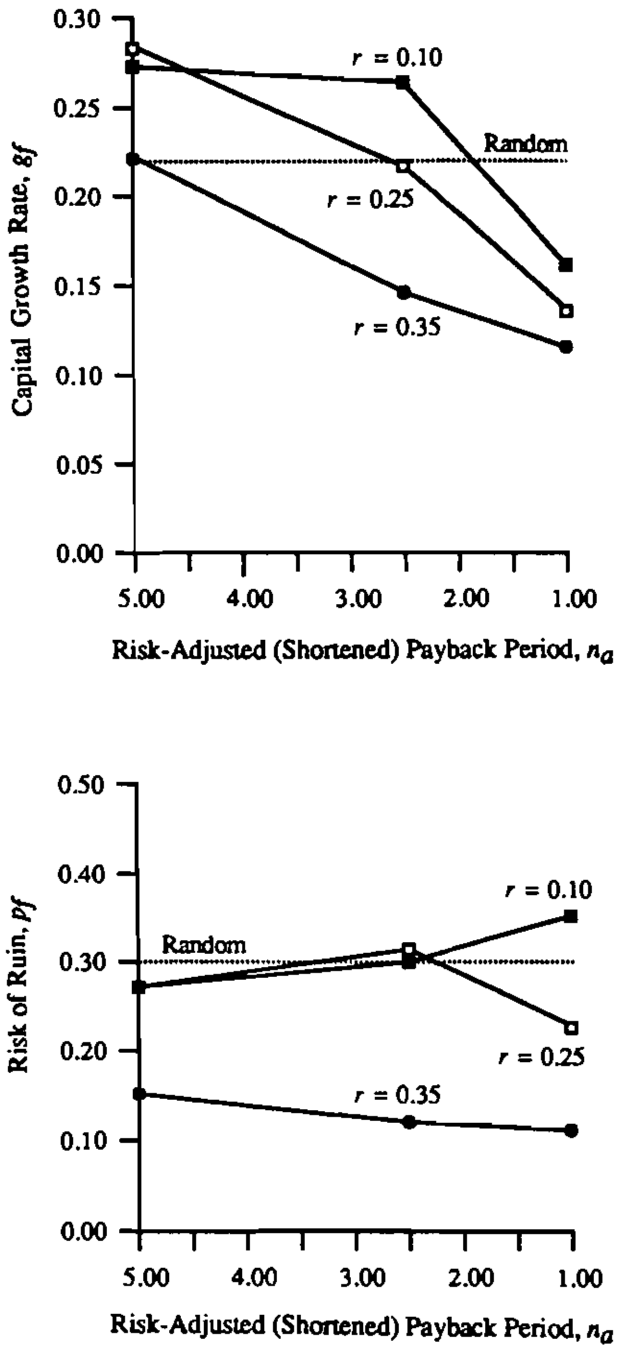


FIGURE 5. Performance of $RNPV/n_a$ with the risk of all long-term investment opportunities perceived correctly.

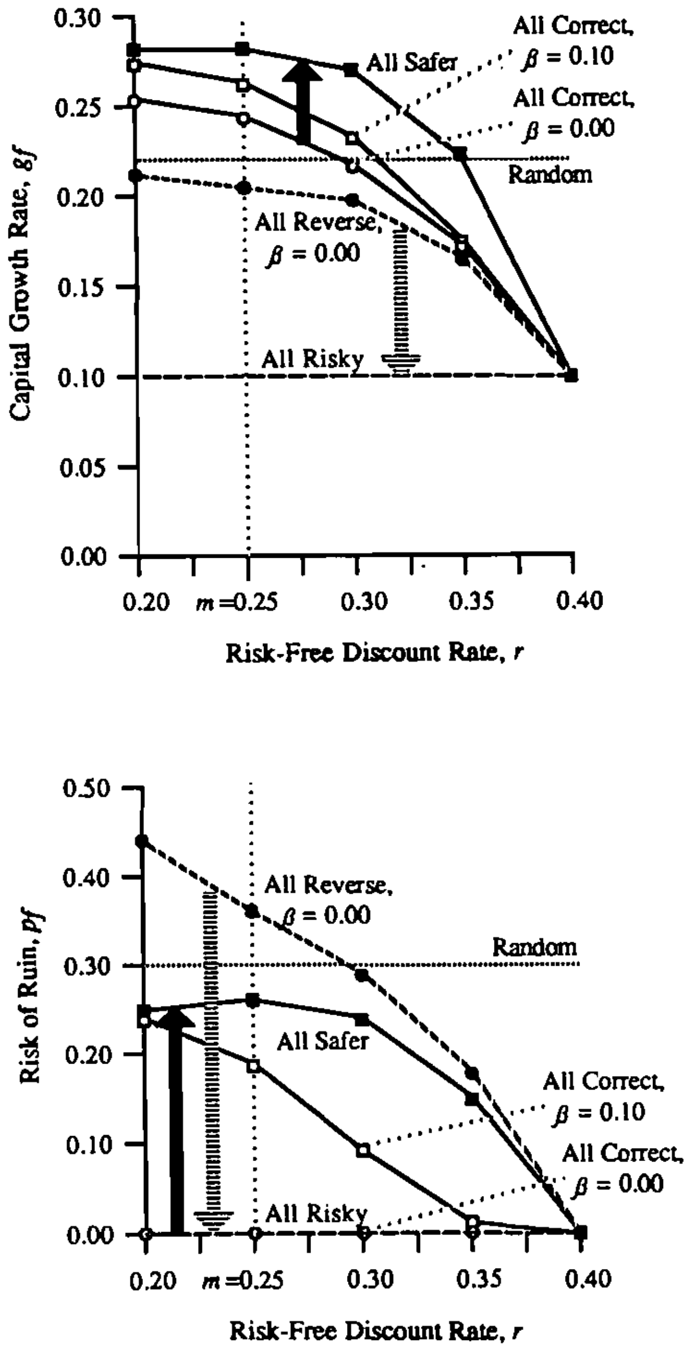


FIGURE 6. Performance of *RNPV/β*

acceptable will be misperceived as unacceptable, whereas one whose risk is unacceptable will be misperceived as acceptable.

The curves of g_f and p_f for values of β = 0.0 and 0.10 are for the situation where the decision maker classifies all long-term investment opportunities correctly. When β = 0.0, all the long-term investment opportunities generated from the risky investment opportunities investment function were rejected, thus making substantial funds available for either safer long-term investments or short-term investments. As the discount rate was increased the result was to divert funds from safer long-term investment opportunities to short-term investments. The substantial amount of capital invested in the market assured that the firm did not suffer ruin and, therefore, the risk of ruin was zero for all r. As the value of β increased, more long-term investment opportunities from the risky investment opportunities function were accepted (with a corresponding decrease of capital invested in the market) increasing both g_f and p_f. In this study, a value of β = 0.20 was sufficient for all long-term investment opportunities to have an acceptable risk. Thus, the curves ("All Correct") approach the situation where the decision maker misperceived the risky long-term investment opportunities as safer ones ("All Safer"), as shown by the solid arrows. In a sense, this later situation ("All Safer") represents the 'upper bound' on g_f and p_f with respect to β for a decision maker who assesses risks accurately.

For the situation where the decision maker misperceives safer long-term investment opportunities as risky, all the long-term investment opportunities were rejected because their perceived risks were unacceptable and thus the budget was invested entirely in short-term investments. Thus, g_f = 0.10 and p_f = 0.0. This situation ("All Risky") represents, in a sense, a 'lower bound' for β.

The situation where the decision maker misperceives both risky and safer long-term investment opportunities is shown for β = 0.0 Values of β between 0.0 and 0.20 would produce curves in the region shown by the dashed arrows.

As noted before, a discount rate of m = 0.25 maximized g_f for the situation where the decision maker perceived all the long-term investment opportunities as safer. The risk of ruin was reduced by either increasing the discount rate, r, or decreasing the acceptable probability of risk, β. Figure 6 indicates that, in general, decreasing β for a given discount rate reduced the risk of ruin more than otherwise could be gained for a given β and increasing the discount rate. It is also noted, again, that estimating the riskiness of long-term investment opportunities accurately is important to realize the benefits of the risk restriction.

EXPERIMENT 5: PREFERENCE FOR SHORT-TERM CAPITAL RECOVERY

A final experiment investigated the notion that recovering one's investment sooner than later reduces one's exposure to risk. Payback Period, in particular, favors such a policy by selecting long-term investment opportunities that return the investment sooner.

In this experiment, two firms were simulated. The characteristics of the long-term investment opportunities were the same as in the previous experiments except that one firm generated only 'long-term' investment opportunities with lives of one period and the other firm generated long-term investment opportunities with lives of five periods. (In the later case, cash flows occurred over the five periods, not just at the fifth period.) Both firms judged the riskiness of long-term investment opportunities correctly and they used $RNPV/r_a$ as the decision procedure with values of r_a = 0.20, 0.25, and 0.30. The results are as follows.

	Lives of Long-Term Investments			
	1 Period		*5 Periods*	
r_a	g_f	p_f	g_f	p_f
0.20	0.261	0.55	0.238	0.03
0.25	0.247	0.51	0.238	0.05
0.30	0.209	0.41	0.222	0.02

The differences between the values of g_f for the two firms were not as striking as the differences in p_f. *In the situation simulated, the preference for short-term capital recovery not only failed to reduce the risk of ruin but it actually increased it drastically.* Although the firm with the short-lived investment opportunities invested a larger amount of funds at each decision time and this large turnover resulted in a diversification which is consistent with the desire to reduce the risk of ruin, another form of diversification occurred in the other firm that was obviously more beneficial. The budget at each decision time for the firm with one period investments was comprised of returns from investments in the immediate preceding period only whereas for the firm with five period investments it was comprised of returns from the five preceding decision periods. The result was that this 'longitudinal' budget diversification had a greater effect on reducing the risk of ruin in the later firm than in the former. In effect, the random cash flow outcomes from several preceding decisions had a significant ameliorating effect on the risk of ruin that was absent when random cash flow outcomes were based solely on the immediately preceding decision. Thus, frequent reinvestment does not necessarily reduce risk.

CONCLUSION

The decision procedures relying on subjective assessment of an opportunity's riskiness, $RIRR/r_a$, $RNPV/r_a$, $ROPP/n_a$, and $RNPV/n_a$, proved, in general, to be marginally effective in dealing with the risk of ruin and attaining the decision maker's objective of maximizing future value. The reduction in risk of ruin attained by either increasing the risk-adjusted discount rate or decreasing the cutoff payback period by these decision procedures was due principally to diverting funds to either safer long-term investment opportunities or market investments rather than to any inherent risk assessment. This was not unexpected since these decision procedures do not measure risk, they only reduce the economic attractiveness of opportunities the decision maker deems risky. Further, accurate assessment, or perception, of an opportunty's riskiness is important to gain the benefits of attaining higher capital growth rates and lower risks of ruin with these decision procedures. Indeed, under some circumstances one can do worse than random selection. Payback Period was reasonably effective in achieving capital growth rates near those attainable with the other logical decision procedures, but it was especially ineffective in dealing with risk. The decision procedure based on objective assessment of risk, *RNPB/β*, was more effective in achieving high capital growth rates and controlling the risk of ruin. Like the other decision procedures however, accurate risk asssessment was important to gain from its benefits. Finally, the decision strategy to prefer long-term investment opportunities with short-term capital recovery periods rather than longer periods was not only an ineffective strategy for controlling risk, it actually increased it drastically.

The use of Monte Carlo computer simulation, of course, does not provide conclusive proof of the performance of capital budgeting decision procedures for dealing with risk for all situations. However, the methodology does offer opportunities to gain insights under fairly complicated and realistic scenarios that serve to enrich our understanding of the relative performance of these techniques.

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