THE RELATIVE PERFORMANCE AND EFFECTIVENESS OF DECISION PROCEDURES FOR DEALING WITH RISK

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ABSTRACT

The relative performance and effectiveness 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 subjective or objective risk assessment and used common measures of worth: Net Present Value and Internal Rate of Return, both with 'risk-adjusted' discount rates, Payback Period, and Net Present Value with a probability-based risk restriction; the sixth decision procedure was random selection. Also investigated were the effects of errors in risk assessment as well as a common risk avoidance 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 suggested in the literature for dealing with risk and surveys of practitioners report that they do use a variety of decision procedures to address risk. However, the performance and effectiveness of these decision procedures in dealing with risk and also attaining the decision maker's financial objective 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 different 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 using Monte Carlo computer simulation of long sequences of capital rationing decisions to evaluate the long-term performance on the capital capital growth rate and risk of ruin of simulated firms using one of six capital budgeting decision procedures for dealing with risk [1]. Five decision procedures used common measures of worth, either Internal Rate of Return (IRR), Net Present Value (NPV), or Payback Period (PP), as the measure of economic merit. Similarly, they exhibited common approaches for dealing with risk. Four decision procedures used either 'risk-adjusted' discount rates or 'risk-adjusted' cutoff payback periods for dealing with 'risky' investment opportunities. Three of them, Rank on IRR with risk-adjusted discount rate, r_a, hereafter $RIRR/r_a$, Rank on NPV with risk-adjusted discount rate, r_a, hereafter $RNPV/r_a$, and Rank on PP with risk-adjusted payback period, n_a, hereafter $ROPP/n_a$, address risk by relying on the decision maker's subjective judgment of the 'riskiness' of an investment opportunity. If deemed risky, then either a risk-adjusted (higher) discount rate, r_a, or a risk-adjusted (shortened) payback period, n_a, is used to judge the attractiveness of the opportunity. The fourth decision procedure, hereafter noted as $RNPV/n_a$, uses Rank on NPV as the primary measure of economic merit and Payback Period as a secondary measure to screen out investment opportunities deemed too risky (as evidenced by unacceptable payback periods). A fifth decision procedure uses NPV and a probability-based risk restriction to assess risk objectively, namely, Rank on (expected value) NPV with an objective risk restriction applied to the NPV distribution, hereafter noted as $RNPV/\beta$. A sixth decision procedure, Random Selection, was also included in the study as a comparative benchmark.

Common to five of the decision procedures is that each opportunity's 'riskiness' must be assessed, and, consequently, it is possible for a decision maker to err in assessment of an opportunity's risk. That is, a decision maker may misperceive an opportunity as risky and evaluate it accordingly (and perhaps reach a different decision). 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.

The purpose of this study was, in general, 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 and, in particular, to obtain insights into the relative performance of these decision procedures. Related research has yielded valuable insights for decision procedures that do not consider risk [16][17][20][21][22][24][25][35]. This study serves to contribute that body of knowledge as another step toward better 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 used in practice and discussed in the literature for dealing with risk 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][12][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. Cash flows were adjusted subjectively by 19%. Kim and Farragher [12] 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 stochastic linear programming, linear programming under uncertainty, chance constrained programming, and goal programming [2][11][28].

Surveys of capital budgeting practices generally have not been designed to assess directly the use of advanced methods, however, Kim and Farragher [12] report that some of the management science methods used are linear programming, 19%, mathematical programming, 13%, decision theory, 12%, and goal programming, 7%. It can be postulated that some of these methods are used in practice to deal with risk [26]. Nonetheless, it has been observed that although "capital limitations do exist, mathematical programming is not so commonly used. Perhaps management is uncertain about the utility of such techniques and doubts the benefits to be derived from their use and is unwilling to expend the resources required for the analysis." [6] Other authors contend that mathematical programming solutions to investment decision analysis confer benefits insufficient to justify their costs [10][21].

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

Some Terms and Definitions

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), has been suggested 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* is when the outcome of a random event is not known *a priori*, regardless of whether the probability distribution that governs 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 *risk of (economic) loss* is the probability of not achieving a specified target return, and the *risk of ruin* is the probability of insolvency. Thus, as used in this paper, uncertainty conveys nothing about the undesirability (or desirability) of the possible outcomes, 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 drawbacks to a ranking decision procedure are that it does not necessarily consider increments of investment (i.e., an incremental analysis) nor does it optimize the investment of the budget in the sense of maximizing future wealth, both of which would be accomplished 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. Among the more computationally simple decision procedures is to classify opportunities into risk classes according to the subjective judgment of the decision maker and then to subject the opportunities to more stringent hurdles of economic acceptability according to their risk class; whereas among the more sophisticated decision procedures is to evaluate the risks of all opportunities under consideration according to an objective probability-based measure, and those whose risk (probability) exceeds a specified acceptable probability are rejected. A major issue in either case is the importance of assessing the 'riskiness' of an opportunity accurately.

The following six decision procedures were studied. Five can be characterized as ranking, risk assessment decision procedures; the sixth was random selection.

Rank on NPV with Risk-Adjusted Discount Rate, $RNPV/r_a$

In this decision procedure opportunities are ranked according to their (expected value) NPV and each opportunity's NPV is computed using a specified 'risk-adjusted' discount rate, r_a, for the risk class to which an opportunity is judged to belong. Opportunities that are 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 'risk-free' class can be viewed as a special risk class (no risk or virtually no risk worthy of special consideration) with its own appropriate discount rate, which we will refer to as the 'risk-free' discount rate. The decision rule associated with the measure of worth NPV in this decision procedure is that opportunities with a positive valued NPV are considered acceptable.

The philosophy for dealing with risk underlying $RNPV/r_a$ is by use of expected value 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, in this case the net cash flow values can be described as the decision maker's perception of the expected values. Opportunities deemed risky have their attractiveness reduced relative to otherwise safer opportunities by increasing the discount rate with the addition of a so-called risk premium. 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 of risky opportunities among themselves.*

Rank on IRR with Risk-Adjusted Discount Rate, $RIRR/r_a$

In this decision procedure 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 measure of worth IRR for each opportunity and a risk-adjusted discount rate, r_a, is then used to judge an opportunity's economic merit according to the risk class to which it belongs. Opportunities deemed not risky are judged using the risk-free discount rate, r. The decision rule associated with the measure of worth IRR in this decision procedure is an investment opportunity is considered acceptable if its IRR exceeds r_a. (For 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, see [14][19]. This paper does not delve into these issues.)

The philosophy for dealing with risk underlying $RIRR/r_a$ is similar to $RNPV/r_a$ but with one notable difference. *The use of a higher dicount 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.* It is also noteworthy that although Ranking on IRR generally violates the principle of decisions based on differences, studies have shown nonetheless that it performs relatively well despite this theoretical deficiency [16][20][25]. Despite this and other difficulties (e.g., multiple IRRs, etc.), it remains popular in practice probably due to its intuitive appeal and familiarity with practitioners who are used to thinking in terms of percentages and ratios.

Rank on Payback Period with Risk-Adjusted Cutoff Payback Period, $ROPP/n_a$

In this decision procedure 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. It is typically computed using the risk-free discount rate, r. (A common variation is "undiscounted" payback period setting $r = 0$.) 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 in this decision procedure is 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. In reality, $ROPP/n_a$ does not address uncertainty (hence, nor risk) but there are those who nonetheless extoll its virtues in dealing with uncertainty. Be ignoring "distant" cash flows, it is advocated that $ROPP/n_a$ recognizes that risk (actually uncertainty) increases with time [34]. 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, it is not clear that receiving funds sooner is better for the firm. This decision strategy of choosing opportunities with a short-term capital recovery was studied in one of our experiments.

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 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 [12][26]. Typically, some measure of worth, usually either NPV or IRR is used as the primary measure to screen opportunities and those opportunities remaining are screened further by selecting from them those that also satisfy a Payback Period requirement. The decision procedure studied here used NPV as the primary measure of economic merit and Payback Period as a secondary measure to deal with risk. The decision procedure is to use *RNPV*, using a risk-free discount rate, to identify an acceptable set of opportunities and then to select opportunities that also meet a specified cutoff payback period, n_a. The underlying philosophy for this decision procedure 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*

In this decision procedure opportunities are ranked according to their expected value NPV, using a risk-free discount rate, and those with non-positive NPVs are discarded. It then screens further opportunties that do not meet the risk restriction of the probability of an undesirable NPV. Thus, Rank on NPV with risk restriction on NPV, *RNPV/β*, selects opportunities with a positive expected value NPV and an acceptable probability, β, of being economical; that is, opportunities must satisfy the risk restriction that the probability of an NPV less than a specified upper limit on undesirable values is less than β. A typical value for the upper limit on undesirable NPVs could be NPV = 0; this was the value used in our experiments.

The underlying philosophy with this decision procedure is that selecting opportunities that have only a small risk of economic loss (of not meeting a "target return" [6]), the risk of ruin of the firm can be reduced. An alternative probability-based risk restriction could be formulated for the net cash flows of individual opportunities. That is, only opportunities with acceptably low probabilities of having undesirable net cash flows would be selected. 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. A principal tradeoff between these two approaches is that risk restrictions on the net cash flows penalizes opportunities with a high probability of future net cash flows being either too small or too negative by ignoring the possible effect of 'averaging out' large net cash flow variations across opportunities that is not otherwise a penalty with the risk restriction on the NPV only. In this sense, risk restrictions on the net cash flows could represent a more conservative 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. Other probability-based procedures could also be studied with the simulation approach we have used.

Random Selection

In this decision procedure 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 reduce the reliability of the information used, the performance of the logical decision procedures would approach that of random selection [16][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 FRAMEWORK FOR EVALUATING DECISION PROCEDURES

There are basically three avenues to investigate issues in capital budgeting decision making: real firms, analytic approaches, and Monte Carlo computer simulation. 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 deifne fairly complicated situations. It, of course, poses it own problems, such as appropriate model development, design of meaningful experiments, and defining measures of performance.

Computer simulation in capital budgeting is not new. Early uses studied capital budgeting under uncertainty involving complete information [7][8][31]. In 1967, 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 [16] 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 framework 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 experiements.

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 began 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 investment in the firm's business. The budget available for investment at the decision time is comprised of returns received currently from investments made in the past. In this model, no borrowing is allowed. 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. Thus, the budget available at each decision time will include the returns to be received at the decision time from both the long-term investments made previously as well as the short-term investments, if any, made at the preceding decision time.

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 [15]. Since the decision procedures studied are intended to help a decision maker avoid such circumstances, we chose a definition of 'ruin' 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 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. (These measures of performance will be discussed further subsequently).

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 and the measures of performance used to evaluate the simulation results are more central and critical elements of the simulation and they need to be described more substantively.

Generation of Long-Term Investment Opportunities

Very little has been published on the long-term investment opportunities generation process of firms except for Viafore's in depth study involving several large firms [32]; although even here 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 random realizations from an investment opportunity 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 values 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 selection decision, but 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 [16][21][22]. The decision procedures in these studies, however, did not include consideration of risk. Thus, this study focused on errors in estimation related to *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 estimation related to risk assessment were modeled in DURSIM 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/ß*, the probability of undesirable NPVs would be computed for each opportunity.) Another version was also generated from the input distributions that represented the returns to be realized if the opportunity was selected. The decision maker, of course, would learn about these values only over time as the returns were realized and used to compose the budget at each decision time. Thus, the decision maker would use the version representing the expected value net cash flows for decision making, and the opportunities selected would yield over time the version representing the realized net cash flows.

The effects of errors in estimation related to risk assessment were modeled as part of the global characteristics used to simulate the generation of long-term investment opportunities under capital rationing; these were: the degree of capital rationing (restrictiveness of the budgets), the distribution of IRRs of the long-term investment opportunities, and the 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 the horizontal portion represents short-term (market) investment opportunities 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 IRRs of long-term investment opportunities were generated by random sampling from the investment opportunities function shown.

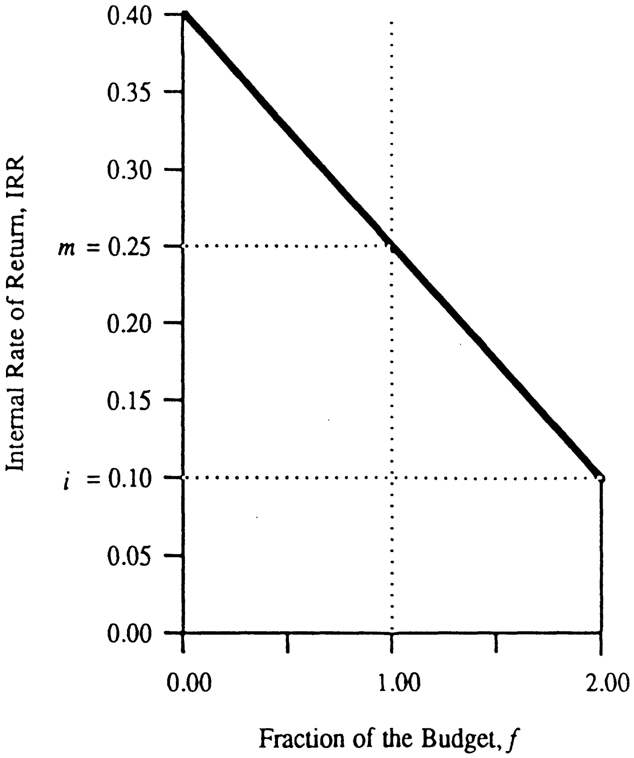

Figure 1 - Investment Opportunities Function

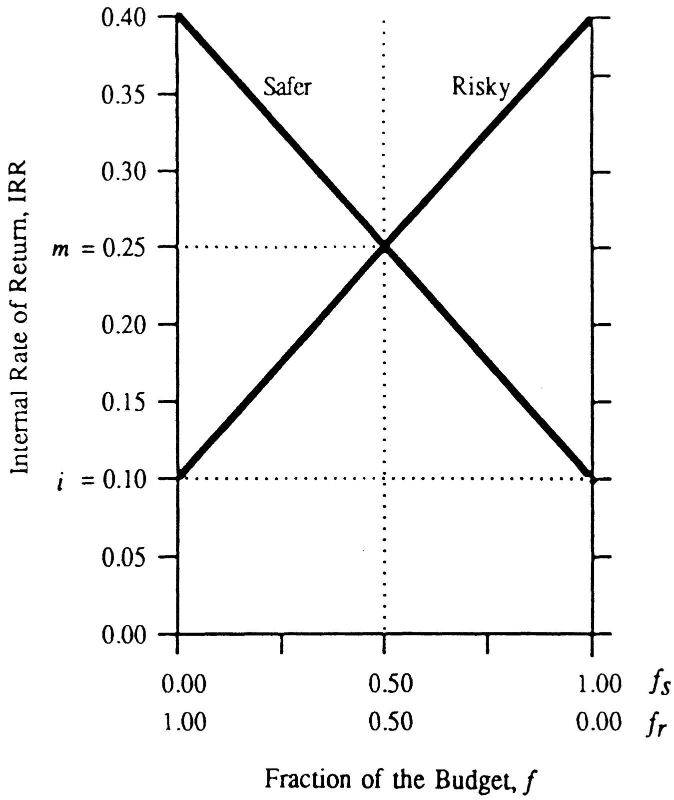

Figure 2 - Safer and Risky Investment Opportunities Functions

Each long-term investment opportunity generated also involved generation of its uncertainty and risk. The decision maker's perception of a long-term investment opportunity's risk is important because the decision about the opportunity could be effected if the risk is misperceived. In practice, long-term investment opportunities can be envisioned that span a broad range of risk from none (or virtually none) to extremely speculative. We chose for our study to classify long-term investment opportunities into only two risk 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 <u>both</u> risk classes involved risk - one less, the other more.*

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 to safer long-term investment opportunities is, 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 it was the effects on the decision maker's selections due to errors in estimation related to risk assessment that was of interest in this study, and not the manner by which the decision maker made such errors, the model needed only reflect the effect on the selections and not necessarily the process by which it occurred. Thus, the model reflected the notion that because of errors in estimation of cash flows or cash flow distributions, a decision maker could misperceive a long-term investment opportunity's riskiness and either select it when it should have otherwise been rejected or vice versa.

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 different cutoff hurdle than would otherwise have been the case. For the situation where long-term investment opportunities were judged safer, the cutoff hurdle was 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). Otherwise, either a higher value of r_a or a lesser value of n_a was used for long-term investment opportunities judged risky.

For the decision procedure $RNPV/\beta$, the effect of errors in estimation related to risk assessment were modeled as follows. This decision procedure, unlike the others discussed above, accounts for risk objectively based on the distribution of the NPV computed from the distributions of the net cash flows. If a decision maker erred in estimating the net cash flow distributions of an opportunity, then the risk perceived (assessed) would also likely be in error. Because the probability-based risk restriction on NPV associated with *RNPV/ß* serves only to screen out long-term investment opportunities with risks perceived unacceptable, only one of two outcomes could occur that would adversely affect a decision about a long-term investment opportunity because of a misperception in its risk, either an opportunity whose (true) risk is acceptable would be misperceived as unacceptable and the opportunity rejected or an opportunity whose (true) risk is unacceptable would be misperceived as acceptable and the opportunity may be accepted, subject to capital rationing constraints. Thus, we need only model the process whereby the (true) risk is calculated from the specified (input) distributions and the effect on the decision due to misperceptions in risk is accounted for in the investment selection process. Therefore, in applying the decision procedure *RNPV/ß,* 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 just 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.

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 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).

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][13][17][23]. All of them, however, are based on the output budget vectors. One of the results (output) of a (finite) sequence of decisions is a budget (cash flow) vector whose first value occurs one period after the last decision in the sequence. It 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 [16][20][24]. Consequently, a surrogate measure was used [1]. 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, gf, 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 result (output) from the simulation is the risk of ruin of the firm. Among the alternative ways this can be measured, we chose to define the risk of ruin of a firm, pf, as the relative frequency (probability) of the number of replications of a sequence of decisions that resulted in ruin (on or before the specified termination time for the sequence) [1].

Thus, for each simulation of a long sequence of capital rationing decisions involving risk, we obtained two scalar measures of performance, $\{gf, pf\}$. Judgment is required in the tradeoffs between values of gf and pf in comparing the results of simulation experiments. If gf is higher and pf 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 gf and pf. 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.

FIVE SIMULATION EXPERIMENTS

Five simulation experiments were performed to observe: 1) the performance of $RIRR/r_a$ and $RNPV/r_a$, 2) the performance of $ROPP/n_a$, 3) the performance of $RNPV/n_a$, 4) the performance of $RNPV/\beta$, and 5) the effectiveness of 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 but the results are not presented here; as can be expected, these experiments produced results that are 'bounded' by the four cases above.

A comparison and evaluation of specific data points produced by one decision procedure with the data points produced by another decision procedure was difficult in some cases since either: 1) the values of gf and pf required subjective judgment of the tradeoffs between (typically) a higher gf or a lower pf, 2) 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 3) 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 Figure 3. 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. (An appropriate alternative risk-free discount rate would be the marginal growth rate, m. Simulations were performed using m as the risk-free discount rate and these results are noted subsequently below.) The results for both decision procedures were very similar, and not too surprising in light of similar observations in related research [16][20][24][25]; consequently, the results for both will be discussed simultaneously.

In general, the decision procedures performed about equally well and were more insensitive for values of $r_a < m$ than for values of $r_a > m$. It is noticeable that 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. It is noticeable that 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 Figure 3), the values of gf and pf 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 treated every long-term investment opportunity as risky ("All Risky" in Figure 3), 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 gf and pf for $RIRR/r_a$, but somewhat less so for $RNPV/r_a$, to values of $r_a < m = 0.25$ for most risk misperceptions was because the budget, on the average, was

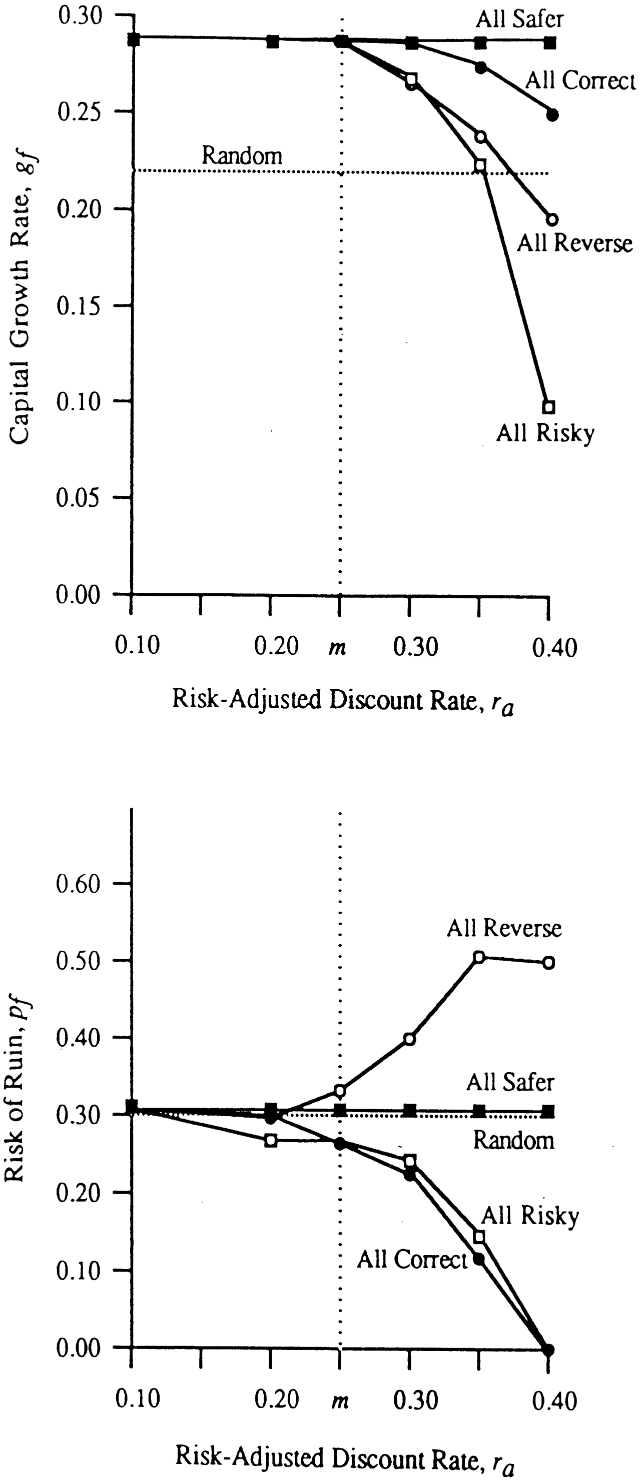

Figure 3 (a) - Performance of *RIRR*/r_a

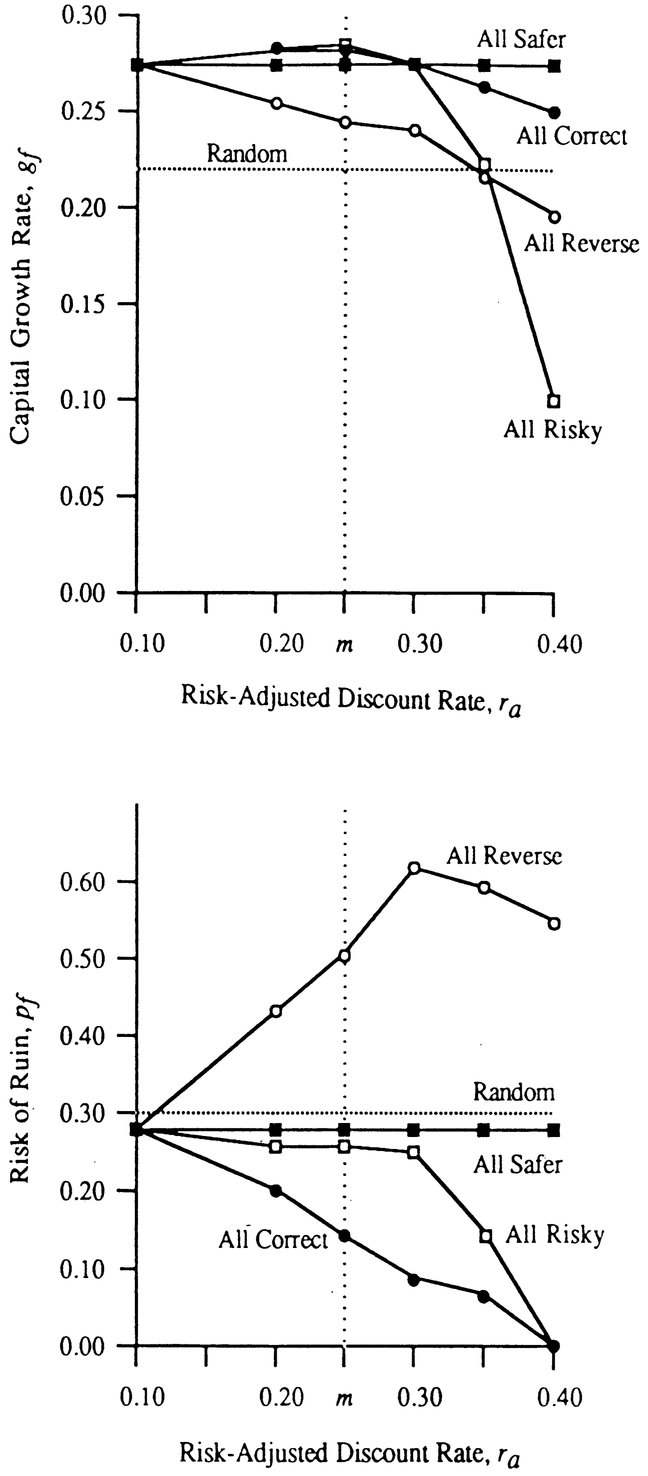

Figure 3 (b) - Performance of *RNPV*/r_a

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 $r_a > 0.25$, for all risk misperceptions except when all opportunities were perceived safer, funds were diverted either to risky long-term investment opportunities from the safer ones ("All Reverse") because the risky ones were misperceived as acceptable or to 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 Figure 3 that accuracy in risk assessment is important to derive the benefit of a high *gf* and a low *pf*. 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 assessment.

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 *gf* and *pf*.

Experiment 2: The Performance of $ROPP/n_a$

Figure 4 shows 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. Panel (a) shows the results when the risk-free discount rate used to compute the Payback Period was $r = i = 0.10$, and panel (b) shows the results when $r = m = 0.25$ was used. The cutoff payback period for long-term

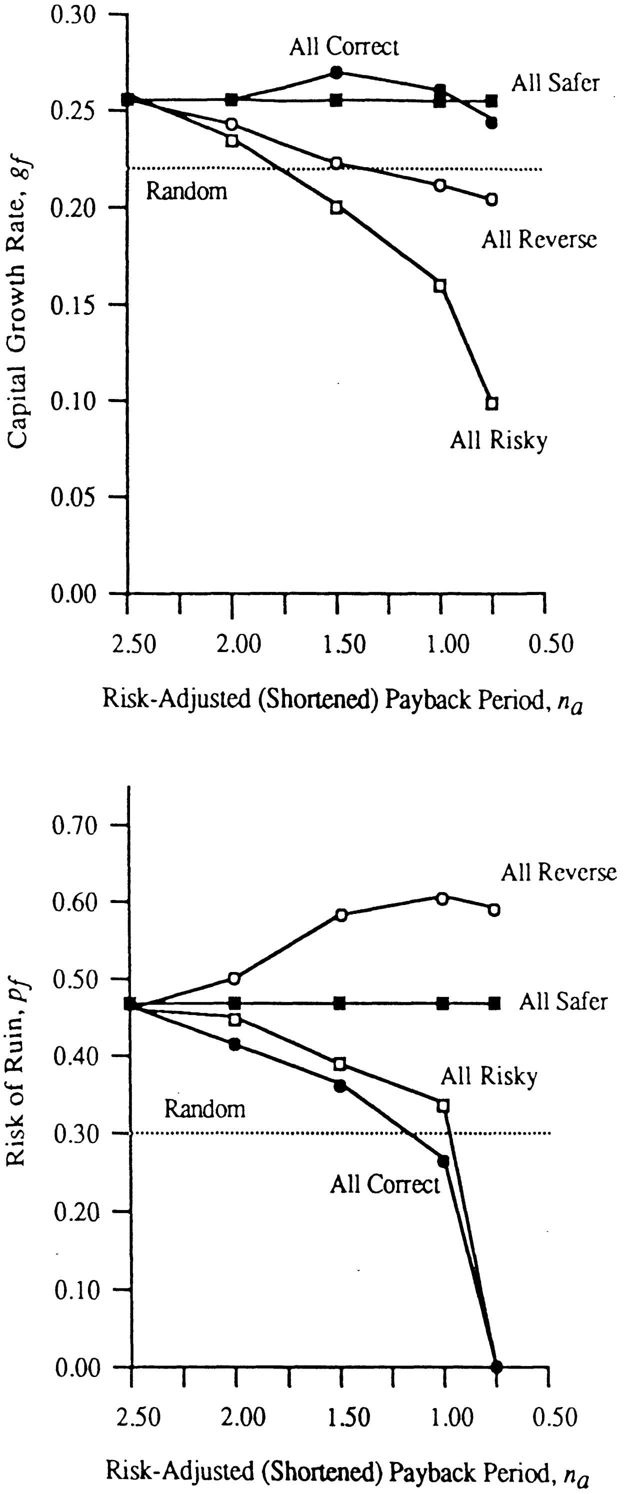

Figure 4 (a) - Performance of $ROPP/n_a$ with risk-free discount rate $r = 0.10$.

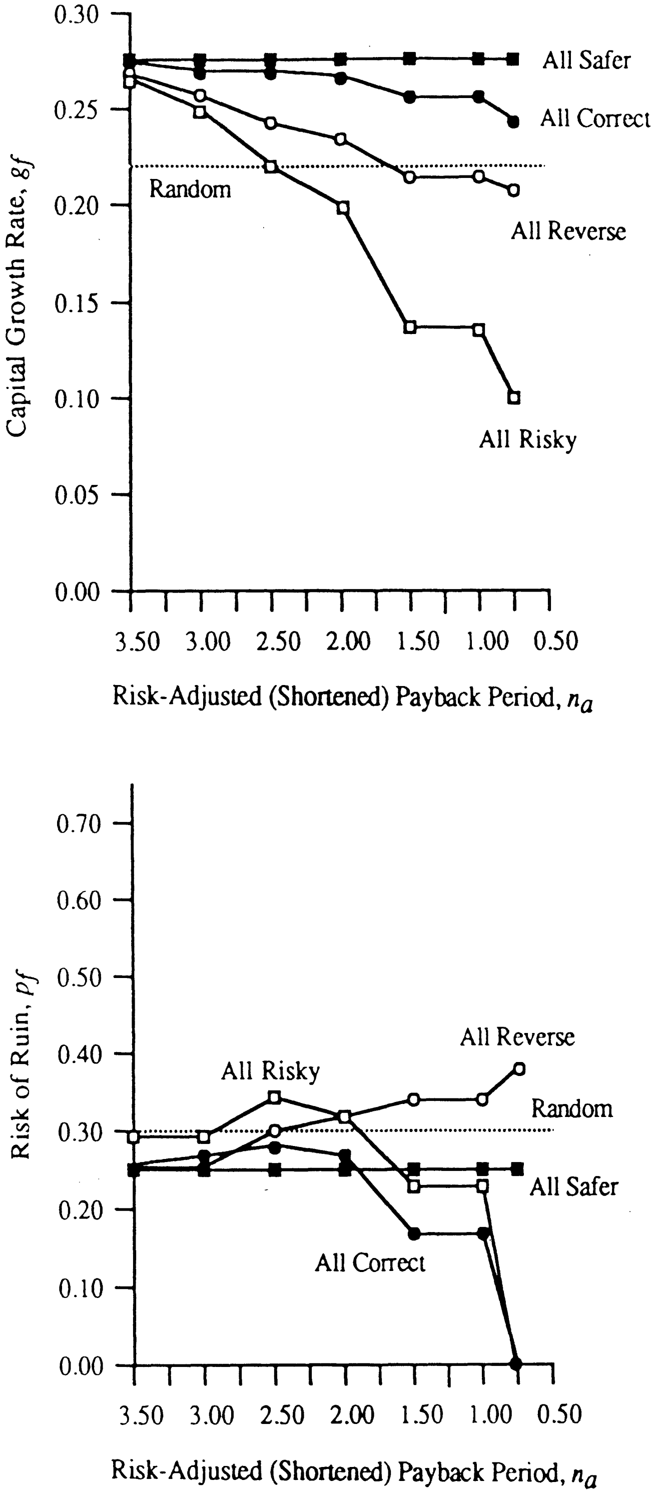

Figure 4 (b) - Performance of $ROPP/n_a$ with risk-free discount rate $r = 0.25$.

investment investment opportunities perceived safer was 5.0, thus guaranteeing, for the situation simulated, that no long-term investment opportunity perceived safer was rejected for failure to satisfy this hurdle since all the long-term investment opportunities generated in these simulation experiments had a payback within 5 periods.

In examining Figure 4, it is important to recognize that the discount rate used has 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. Therefore, the $ROPP/n_a$ decision procedure screened out at least a subset of long-term investment opportunities that were also rejected by $RNPV/r_a$ and $RIRR/r_a$ for a given discount rate. Thus, $ROPP/n_a$ in a sense contains implicitly some economic elements equivalent to $RNPV/r_a$ and $RIRR/r_a$.

Focusing on panel 4 (a) for the moment, we note that *gf* and *pf* for the situation where the decision maker perceives all long-term investment opportunities as safer (that is, only the risky ones are misperceived) plot as horizontal lines 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 from Figure 3 (previously) 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 maximize future wealth, 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 imay 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 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 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 panel 4 (b). The most notable effect from raising the risk-free discount rate used to compute the Payback Period from $r = i = 0.10$ to $r = m = 0.25$ was the impact on the risks of ruin. For values of $r > 0.10$, the performance of $ROPP/n_a$ improved (gf was higher and pf 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 increasing values of n_a, the improvement in pf 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 gf, lower pf) 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 n_a 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 discount rates above and below m 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

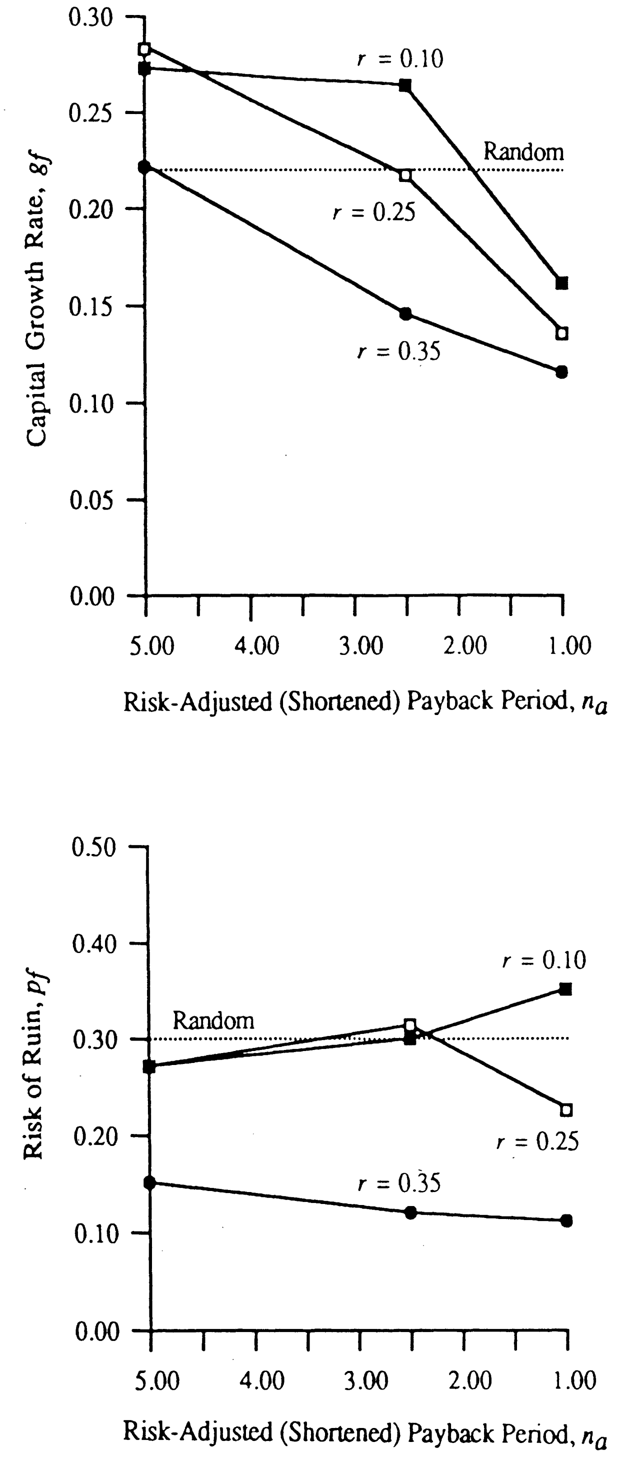

Figure 5 - Performance of $RNPV/n_a$ with the risk of all long-term investment opportunities perceived correctly

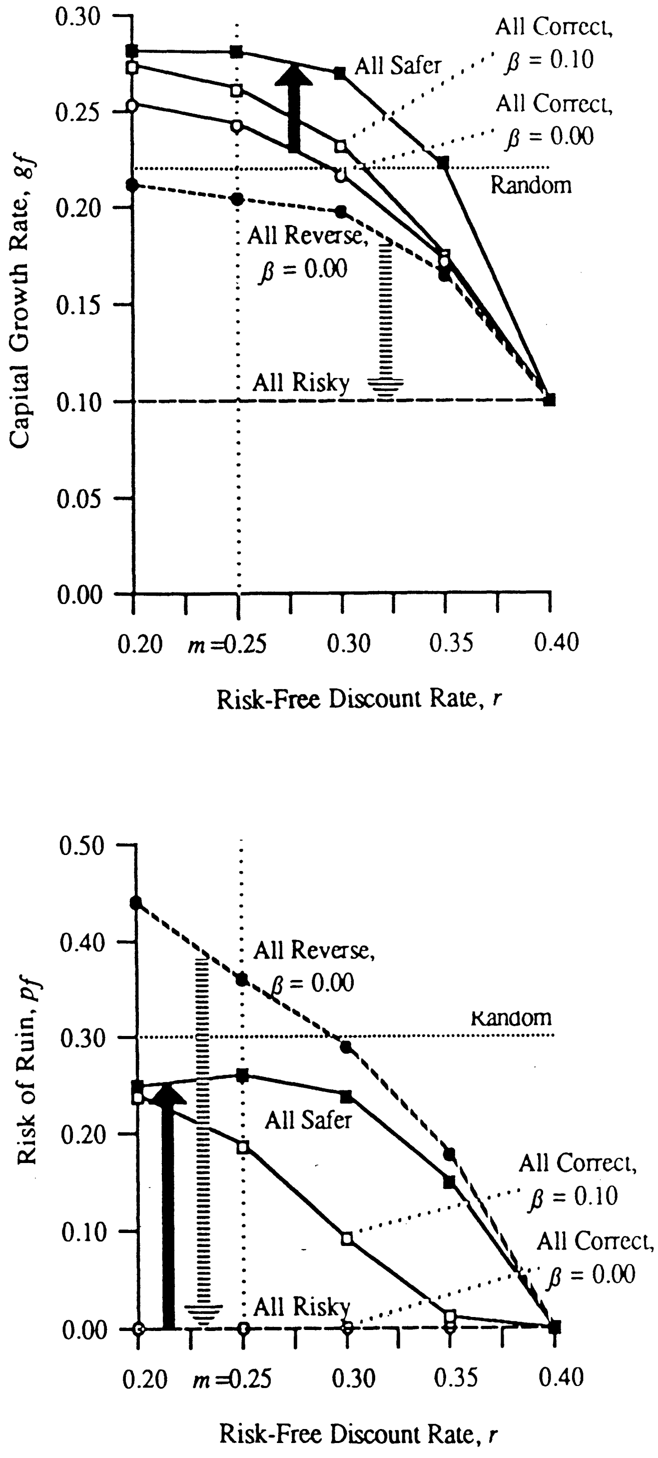

Figure 6 - Performance of $RNPV/\beta$

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: increased steadily for $r = 0.10$, remainded essentially constant for $r = 0.25$, and decreased steadily for $r = 0.35$. This 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 of the capital growth rate.

Experiment 4: The Performance of *RNPV/β*

Figure 6 shows the results of the performance of *RNPV/β* for values of $\beta = 0.0$ and 0.10 (and implicitly, $\beta = 0.20$), and risk-free discount rates between 0.20 and 0.40. It is to be remembered that for *RNPV/β* 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/β* 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 the risk computed leads the decision maker to judge the risk opposite of what would have been judged otherwise had the decision maker made no errors in estimation. That is, a risky long-term investment opportunity whose (true) risk is acceptable will be misperceived as unacceptable, whereas one whose risk is unacceptable will misperceived as acceptable.

The curves of gf and pf for values of $\beta = 0.0$ and 0.10 are for the situation where the decision maker classifies all long-term investment opportunities correctly. In the situation studied, when $\beta = 0.0$ all the long-term investment opportunities generated from the risky investment rate as the discount rate increased was the result of diverting 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 gf and pf. In this study, a value of $\beta = 0.20$ 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 gf and pf 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, $gf = 0.10$ and $pf = 0.0$. This situation ("All Risky") represents, in a sense, a 'lower bound' with respect to β.

The situation where the decision maker misperceives both risky and safer long-term investment opportunities is shown for $\beta = 0.0$ Other 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 gf 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 a probability-based 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. 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 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 shown in Table 1.

TABLE 1

Preference for Short-Term Capital Recovery

	Lives of Long-Term Investments			
	1 Period		5 Periods	
r_a	gf	pf	gf	pf
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 gf for the two firms were not as striking as the differences in pf. *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 '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 an ameliorating effect on the risk of ruin that was greater than the effect of random cash flow outcomes of only an 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, $RNPB/\beta$, 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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