Risk Propensity and Firm Performance: A Study of the Petroleum Exploration Industry

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This paper explores the differences in observed risk propensity among petroleum firms and their impact on firm performance. In this work, we (1) develop a decision theoretic model which measures a firm's risk propensity in the form of an "implied" utility function; (2) investigate changes in corporate risk propensity with respect to changes in firm size; and (3) examine the relationships between firms' risk propensities and alternative dimensions of economic performance, including ex post risk and return measures. We also develop a new risk propensity measure, the *Risk Tolerance Ratio* (RTR), which controls for firm size and allows firms to be differentiated in terms of *relative* risk propensity. The motivation for this work is managerial concerns regarding appropriate risk-taking behavior and the effect of risky choice on firm performance. This methodology has importance business strategy implications in that we are able to make strong inferences about causal relationships between ex ante risk-taking and performance. Our findings are compelling in that corporate risk propensity seems to matter, and that decisions about corporate risk policy have a significant impact on the petroleum firm's economic performance.
(*Risk Management; Decision Analysis; Exponential Utility; Business Strategy; Firm Performance; Certainty Equivalents; Risk Tolerance*)

1. Introduction

In the decision making context, risk is an ex ante concept; however, it generally is measured in empirical work on organizational performance after the event (ex post), through such measures as variance of returns. This is true in the field of financial economics as well as strategic management. Previous studies of risk-return relations have defined risk as the variation in the firm's income stream (Bowman 1980, Figenbaum and Thomas 1985, Montgomery and Singh 1984), the uncertainty of the outcomes of an organization's resource commitments (Singh 1986), and by the observed ex post variance of a firm's return on investment or equity. Analysis of ex post risk-return relationships generally provides little information about the relationship between the firm's strategic actions and outcomes within a given risky decision environment. Ex ante-ex post comparisons for the evaluation of managerial performance are difficult because access is not available to publicly announced risk policies of firms during the study periods (Brockett et al. 1990). Other researchers have recognized this methodological shortcoming. Woo (1987) and Singh (1986) noted that their models posed untested assumptions concerning the direction of causal relations between risk and return. Bowman (1984) and Brockett et al. (1990) attempted to compensate by looking at measures of risk in one time period and performance in another. Bromiley (1991) measured the risk of a company's income stream for a given year by the variance in security analysts' forecasts of that income. Using a combination of archival data and questionnaire information, Singh (1986) attempted to match findings on managerial attitudes (ex ante) with actual performance (ex post).

Faced with similar investment opportunities in the same product-market environment, differences in risk

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propensity among firms may yield differences in economic performance. The present study is focused on firms in the petroleum exploration industry, and (1) develops a decision theoretic model which measures each firm's risk propensity in the form of an "implied" utility function; (2) investigates changes in corporate risk propensity with respect to changes in firm size; and (3) examines the relationships between a firm's risk propensity and dimensions of economic performance, including both ex post risk and return measures.

Archival data are examined which represent actual resource commitments by petroleum exploration firms under conditions of risk and uncertainty. Utilizing the exponential utility function ($u(x) = -e^{-cx}$) and these risky resource commitments, we characterize the risk propensity of the firm by a single number, the *risk tolerance* measure. Risk tolerance is defined as the inverse of the risk aversion coefficient, c, in the exponential utility function. Notice that we are using archival data regarding past decisions to estimate a firm's risk propensity, which would seem to imply that we are also measuring a risk attitude ex post. However, we adopt a different point of view and use these data to reconstruct the risky alternatives that firms considered at the time investment decisions were made. By comparing these known decisions with our reconstructed risky alternatives, the implied value of the firm's risk tolerance can be determined.

This approach is similar in spirit to the traditional method for assessing an individual subject's risk propensity ex ante by posing hypothetical lottery questions and asking for the certainty equivalent. Previous research, however, has tended to use settings that are unrealistic and far removed from the actual risks firms face, and those studies have usually been conducted with students as subjects. In the few studies that have been done with practicing managers, the risk measures have been somewhat better, but are still open to doubt in the context of firm-level risk taking behavior. A strength of our approach is that it is based on actual decisions rather than hypothetical lotteries, but a weakness is that the risky alternatives we have reconstructed are only the approximations of the ex ante risks actually perceived by the decision makers.

This study provides a link between *descriptive* and *prescriptive* decision analysis by utilizing empirical findings about risk selection behavior to *prescribe* techniques for aiding decision making. We attempt to extend the notion of what Howard (1988) refers to as a "generic" risk attitude for firms in a particular industry. We also develop a new measure, called the *Risk Tolerance Ratio* (RTR), which allows firms to be differentiated in terms of *relative* risk propensity. Our intent is to utilize the RTR measure to investigate the impact of organizational risk taking on performance. Our findings are compelling in that corporate risk propensity seems to matter, and that decisions about risk policy may have a significant impact on the firm's ability to compete in its industry. This is the focus of our study, and these results make it distinctive from the other studies of risk cited above.

2. Conceptual Development and Propositions

Motivation

This study was motivated by a series of interviews with middle and senior level managers from 26 independent and integrated petroleum exploration firms over a three-year period. A common thread of concern expressed by these managers, in the face of risk and uncertainty, is the question of choosing the appropriate risk-taking behavior for the firm and the effects of this choice on firm performance.

The petroleum exploration industry is fraught with risk and uncertainty; it provides an ideal setting for the investigation of firm-level risk taking behavior and its effects on firm performance. The wildcat drilling decision has long been a prototypical example for the application of decision analysis in classical textbooks (e.g., see Newendorp 1975 and Raiffa 1968). In practice, even when petroleum exploration projects can be evaluated using this approach, management often needs to compare the risk and relative attractiveness of one project characterized by a high probability of success and a relatively low net present value payoff with another project characterized by a very low probability of success and a significantly higher net present value. Although expected value calculations can be a useful means for ranking these projects, it has been our experience that petroleum exploration managers are also concerned about the magnitude of capital being exposed to the chance of loss. In addition, managers also express interest in opportunities for "spreading the risk" of oil exploration projects by taking smaller participation levels in more projects, which implies a risk averse attitude toward these decisions. See Walls et al. (1995) for a discussion of these issues as faced by Phillips Petroleum Company.

Since the risks of oil exploration are so obvious, there may be some concern that the petroleum industry has unique characteristics which may result in different risk-taking behavior than other industries. MacCrimmon and Wehrung (1986) designed their managerial risk propensity study to include the resource industry, financial institutions, and the high-technology industry, but found no statistically significant differences in risk propensity among the major industry classifications in their study, except for slightly more risk-averting behavior associated with the banking industry. Therefore, we do not believe that the conclusions of our study are meaningful only for the petroleum industry.

In the following section, we briefly survey economic theory and empirical studies that support our personal observations that managers, indeed, make decisions in practice that may be described as risk averse. We then consider the forces that may affect the degree of risk aversion that is exhibited in management decisions, and focus on company size as a major factor. Finally, we explore the relationship between the risk propensity of a company and its economic performance.

An Economic Perspective

Modern financial theory views capital markets as the fundamental mechanism for spreading risks. According to this theory, the individual investor has the ability to construct a portfolio that adequately diversifies "business-specific" risk, and managers of a firm should therefore be concerned only about nondiversifiable or "market" risk (Brealey and Myers 1991). Within this theoretical framework, managers in publicly held firms should maximize shareholder value by selecting those investment opportunities which have the highest *expected* net present value. However, this theory is based on a set of idealized assumptions regarding transaction costs, competitive capital markets, and perfect information that are only an approximation of reality.

Greenwald and Stiglitz (1990) have closely examined the economic and risk-taking implications of imperfect capital market information, and argue that firms will act in a risk-averse manner as a result of information problems in the capital market, including asymmetries of information between providers of capital and firm managers. They also show that behavior by managers of the firm that is characterized by maximization of expected profits minus an expected cost of bankruptcy (the cost of bankruptcy times the probability of bankruptcy) is similar to that generated by maximizing a risk averse utility function. Hackett (1985) noted that it is unrealistic to assume that managers are merely agents for shareholders. Instead, managers attempt to reconcile the interests of all stakeholders, including themselves, employees, suppliers, customers, and communities in which they operate.

In addition, the market for corporate control (Jensen and Ruback 1983) could reinforce emphasis on the short term (Loescher 1984) because top corporate officers must demonstrate that their enterprises are viable in each period if they want to keep their positions. The ultimate result of such managerial concerns could be a strong aversion to risky projects in the short term (Hayes and Abernathy 1980).

Managerial Risk Attitudes

Empirical studies of managerial risk attitudes support the theoretical arguments that managers will be risk averse. Swalm (1966) assessed utility functions for a group of 100 executives in a large industrial organization and found the overall attitudes toward risk to be strongly risk-averse. For negative outcomes, he found a slight degree of risk-seeking behavior; however, the steep downward slope of the curves for negative outcomes meant that most gambles have a positive risk premium. Green (1963) conducted another descriptive study involving 16 businessmen in a large chemical company and made similar findings. Spetzler (1968) interviewed 36 corporate executives in a large industrial firm and consistently found risk-averse attitudes, across both the gain and loss domains, among individuals and within the managerial group as a policy making body.

The contributions of Greenwald and Stiglitz (1990) and others who have challenged modern financial theory, and the unanimous conclusions of empirical studies are consistent with our own observations: managers make decisions that may be characterized as risk averse. This conclusion is stated as our first proposition:

PROPOSITION 1. *In the context of the firm, risk-taking behavior can be characterized by a risk-averse utility function.*

Although the reasons that have been suggested for this behavior vary, we believe that the major contributing factor is a mismatch within most organizations between the incentive system for managerial rewards and the objective of maximizing shareholder wealth.

Firm Size and Corporate Risk Tolerance

Economists have generally assumed that the degree of risk aversion of the individual investor decreases as wealth increases. As the firm grows and accumulates additional wealth, its ability to undertake larger, more risky projects also grows. In the petroleum exploration industry, the large exploration budgets available to the major companies allow them to consider simultaneous investments in multiple projects, thereby "spreading the risks" across a diversified exploration portfolio. These portfolios reduce the impacts of probabilistically independent geological and political risks, although they may still be subject to a common dependence on oil prices. However, this common price risk may be hedged (Smith and Nau 1994). Therefore, we would expect larger firms to be relatively less risk averse when evaluating risky exploration projects.

In support of this argument, Howard (1988) has shown in a cursory study of a number of large corporations in one industry that corporate *risk tolerance* appears to grow roughly proportional to financial measures associated with the companies, such as sales, net income, and owner's equity. Howard characterizes the risk tolerance measure, $1/c$, as the sum of money at which the decision makers are indifferent as a company investment to a 50–50 chance of winning that sum and losing half that sum. At least in this case, higher wealth levels are associated with a higher propensity to take on risk,[1] leading to the following proposition:

PROPOSITION 2. *Across firms, a positive relationship exists between firm size and ex ante corporate risk tolerance.*

Within Firm Changes in Risk Tolerance

Systematic changes in certain product-market domains which affect all firms in a particular industry may result in changes in attitudes about capital allocations under conditions of risk and uncertainty. During general economic downturns, or bear markets, most companies face some combination of reduced cash flows, few growth opportunities, and uncertain future cash returns. In such a high-risk–low-return setting, management is likely to be highly risk averse. A natural reaction is to scale back investment programs. For example, within an integrated oil firm, market changes in petroleum product prices are often followed by a shift of funds from the exploration function to the refining function, and vice versa. Reduction of available capital in a given business unit may result in a change in risk tolerance for that unit. Likewise for smaller firms, a shortfall of investment capital and a tight credit market result in a more selective process of decision making, a condition which implies a lower degree of risk tolerance. An opposite pattern of behavior should occur during periods of growth. Flush with cash and facing an attractive set of investment opportunities, management may be less risk-averse when pursuing investment opportunities. We expect to observe that increases in firm wealth are associated with increases in the firm's willingness to take on risk, indicated by higher *risk tolerance* levels. As firms shrink in size, it follows that they should become less willing to take on risk, and thus exhibit lower *risk tolerance* levels.

PROPOSITION 3. *Within firms and across time, a positive relationship exists between firm size and ex ante corporate risk tolerance.*

Proposition 3 is obviously consistent with Proposition 2 in the long term, since we are suggesting that increasing firm size leads to increasing *risk tolerance*. However, Proposition 3 is focused on testing this relationship within firms over a relatively short period of time (eight years in this study).

Corporate Risk Tolerance and Financial Performance

Risk-taking behavior by the firm which is interpreted by credit (i.e., bond ratings) markets as increasing the probability of financial distress or insolvency increases the cost of funds for that firm. This increase in the cost of capital can make once viable projects uneconomic. In

[1] We have attempted to avoid some isolated and peculiar relationships with regard to risk propensity and firm size. For example, entrepreneurs managing start-up firms may be greater risk-takers. We do not include start-up firms, and we limit firm size in this study to a minimum asset base of $50 million.

a homogeneous industry where investment projects have equivalent properties (as in the case of petroleum exploration), competition for scarce capital requires the firm to obtain an appropriate tradeoff between: (1) maximization of expected profits; and (2) the probability of bankruptcy (or financial distress) consistent with the demands of a well functioning capital/credit market.

A linear preference function is optimal in the context of expected profit maximization. As the corporate *risk tolerance* increases, the implied utility function becomes less risk averse, and eventually approaches a linear preference function. However, in order to compensate for the effects of a competitive capital/credit market, the firm's resulting investment decisions are constrained by some degree of risk aversion consistent with the firm's financial strength (i.e., assets, cash flow, etc.). This tradeoff between maximizing value and avoiding "hazardous" levels of risky investment is fundamental to the long term viability of the firm. As noted earlier, Greenwald and Stiglitz (1990) have shown that the objective of maximizing expected profits minus the expected cost of bankruptcy leads to decisions consistent with those determined by maximizing a risk-averse utility function.

In practice, it may be very difficult to estimate the expected cost of bankruptcy, or even the increased costs of funds for the firm that may be associated with perceptions of financial distress. Furthermore, the appropriate tradeoff will be affected by the financial strength of the firm and thus may be different for larger firms than for smaller ones. As a result, we would expect some firms to implement this policy of a tradeoff between expected profits and the expected costs of financial distress more effectively than others, and we would also expect this policy to have an effect on the performance of the firm. That is, the selection of the "appropriate" corporate *risk tolerance ratio* (RTR), a risk propensity measure adjusted for the size of the firm as a proxy for its financial strength, should lead to superior firm performance. An "inappropriate" corporate *risk tolerance ratio* should be associated with lower returns and/or financial distress.

PROPOSITION 4. *Up to some optimal point, beyond which the firm undertakes "hazardous" investments, a positive relationship exists between the corporate risk tolerance ratio and ex post returns.*

Ex Ante Risk versus Ex Post Risk

Finally, we consider the issue of the relationship between the ex ante corporate risk tolerance and ex post measures of risk. Nearly all previous risk-return studies have interpreted an ex post measure of risk (i.e., variance) as representative of the ex ante risk selection behavior of the firm. The ex post risk-return relationship has been generally interpreted as the relationship between the firm's ex ante strategic actions and the resulting ex post outcomes.

Intuitively, one might expect a high correlation between these two risk measures based on the argument that firms more willing to accept risks ex ante will tend to experience higher values of ex post risk measures. If this correlation is sufficiently high, then efforts to measure risk propensity would be of questionable worth. However, if ex ante and ex post risk measures are not highly correlated, then the significance of this effort is enhanced.

PROPOSITION 5. *Across firms, a positive relationship exists between the ex ante corporate risk tolerance ratio (RTR) and ex post risk.*

3. Modeling Corporate Risk Tolerance

Estimating Corporate Utility Functions

Utility theory provides a basis for constructing a utility function which can be used to make risky choices consistent with the risk preferences of the decision maker. While the vast majority of companies do not actually make explicit a corporate utility function, estimating their *implied* utility function through a systematic analysis of decision making under risk is a practical approach to interpreting the firm's risk taking behavior. In our model, past decisions involving allocations for risky investments are the basis for inferring the risk attitude of the firm. Firms making capital allocation decisions under conditions of risk and uncertainty must have some knowledge (objective or subjective) concerning the magnitudes of potential outcomes and the probabilities associated with those outcomes. If they make these decisions rationally and consistently, then their implied risk attitude can be described by the parameters of a von Neumann-Morgenstern utility function (e.g., see Luce and Raiffa 1957, Spetzler 1968). It is also interesting to note that in his study of oil and gas executives, Wehrung (1989) found that more than half of the executives gave responses that were fully consistent with expected utility, and an additional quarter of executives were consistent within a 10% margin of error in their responses.

In order to estimate the firm's implied utility function, a common functional form of utility must be selected. One functional form which is dominant in both theoretical and applied work in the areas of decision theory and finance is the *exponential utility function*, and is of the form $u(x) = -e^{-cx}$, where c is the risk aversion coefficient, x is the variable of interest, and e is the exponential constant. A value of $c > 0$ implies risk-averse behavior, $c < 0$ implies risk-seeking behavior, and c approaching 0 implies risk-neutral behavior.[2] The risk tolerance is simply defined as the reciprocal, $1/c$.

The *certainty equivalent* (C_x) is equal to the expected value less a risk discount, known as the risk premium. In the case of the exponential utility function, the firm's *buying price*[3] for a given risky investment represents its certainty equivalent for that risky investment. The C_x value is, in essence, the "cash value" attributed to a decision alternative that involves uncertain outcomes. For discrete probability distributions, the certainty equivalent of an individual with an exponential utility function is:

$$C_x = -1/c \ln\left(\sum_{i=1}^{n} p_i e^{-cx_i}\right), \qquad (1)$$

where p_i is the probability of outcome i, x_i is the value of outcome i, and ln is the natural log (Cozzolino 1977).

The exponential utility function is employed in this model because it possesses many desirable theoretical properties and has a convenient mathematical representation. Acceptance of the exponential form's property of constant risk aversion ultimately leads to the characterization of risk preference by a single number, the *risk aversion coefficient c*, which, loosely speaking, measures the curvature of the utility function. This permits the use of the parameter c, or its reciprocal the *risk tolerance* (RT), in a comparative manner as an index of risk aversion. Following our proposition #3, it is important to note that a hypothetical firm might make decisions when small that implies one utility function with a specific c value and then when that same firm is larger, investment decisions may reflect a different c value. Even under conditions where the exponential utility function may not describe the firm's risk propensity with complete accuracy, the potential for a close approximation to the true utility function exists.

This point deserves some elaboration. We do not assume nor theorize that all firms in the petroleum industry actually make risky decisions consistent with an exponential utility function. Nor do we assume any specific form of risk-taking behavior, i.e. risk-averse, risk-neutral, or risk-seeking. Rather, we have chosen this form of a utility function to fit to the empirical data because it provides a convenient measure of risk-taking propensity. As our propositions imply, we expect the risk propensities of firms to vary over time, and to be related to firm size in a manner more consistent with decreasing rather than constant risk aversion. However, the robust approximation of the exponential utility function at any point in time provides a snapshot measure of risk propensity that can be studied dynamically and used as a relative measure for comparing firms within an industry group. The single-parameter form of the exponential utility function, coupled with the empirical data available, enables us to capture risk-averse, risk-seeking or risk-neutral behavior at the level of the firm.

The authors recognize that there exist a number of functional forms of utility that one could apply to this generalized approach. Many of these functional forms are a result of recent work in the behavioral decision theory area. For example, if project-level data were available, then prospect theory's S-shaped utility function (Kahneman and Tversky 1979) might serve to distinguish between risk propensity towards projects in the "gain" and "loss" domains. However, use of this and other functional forms would require additional assumptions and further complicate the comparison of firms, a central motivation for this study. In addition, project-level data over this time period and for this number of firms are simply unavailable, so reconstruction of decisions on a project-by-project basis is not feasible. In light of these considerations and the relatively

[2] A thorough discussion of this functional form and its properties may be found in Keeney and Raiffa (1976).

[3] Howard (1984) and Raiffa (1968) have shown that the property of constant risk aversion, as in the exponential and linear forms of utility function, results in equivalence of *buying and selling* prices.

rich data set that is available for analysis, application of the exponential utility function represents an appropriate functional form and enhances the contribution associated with this empirical study.

Stylized Example of Modeling Approach

In the petroleum exploration industry, there exist two broad geographic categories of exploration, domestic and foreign. Suppose a firm chooses to invest in one domestic well and one foreign well, and assume these investment opportunities have estimates of the probabilities of success and failure that are probabilistically independent. Then the probability distribution of outcomes associated with investing in both can be combined into a composite lottery.

Now suppose that the firm's allocation for exploration expense[4] (buying price) for each investment category, domestic and foreign, is known. This budget allocation for each lottery category is interpreted as the certainty equivalent (C_x) for that lottery. Assuming the exponential form of utility, a firm that engages in n independent lotteries has a certainty equivalent for the portfolio of lotteries equal to the sum of the certainty equivalents for each individual lottery. Given the certainty equivalent for this simple composite lottery, the implied risk-aversion coefficient, c, can be determined from the closed form expression in Equation (1).

To extend this idea to the case of multiple investments, the composite lottery approach quickly becomes mathematically intractable. The analysis of a firm undertaking 20 projects a year, for example, would require a composite lottery analysis with 2^{20}, or over 1 million, branches. In fact, many firms participate in more than 20 wells per year. To provide for reasonable computational tractability, we approximate the distribution of exploration outcomes by treating each lottery category, domestic and foreign, as a binomial distribution, a case of the Bernoulli process in which only two outcomes can occur on any given trial. Each trial is an independent event, and the probability of each outcome remains constant over independent trials.

We can make the normal approximation to the binomial distribution even in the case of moderately small n, so long as p, the probability of success, is not close to 0 or 1 (Mendenhall, et al. 1986). A useful rule of thumb is that whenever n times p, as well as n times $(1 - p)$, equals or exceeds 5, then the assumption is reasonable (Kohler 1985). When the sample size is large, the central limit theorem ensures that the sample mean will possess approximately a normal distribution if the random sample is taken from any distribution with finite mean and variance. In the case of the normal distribution of project returns and an exponential utility function, the certainty equivalent, C_x, is equal to the expected value (EV) of the distribution minus one-half the risk aversion coefficient c times the variance (σ^2) (Raiffa 1968); that is

$$C_x = \mathrm{EV} - 1/2c\sigma^2. \tag{2}$$

Even in the case where returns are not normally distributed, Equation (2) provides a good approximation for small values of c.

Figures 1(a) and 1(b) provide a stylized example of this approximation technique and the comparisons of the use of Equations (1) and (2). In Figure 1(a), a discrete probability distribution of outcomes faced by a hypothetical firm is indicated by the bars in the graph. A normal approximation of that same distribution is indicated by the solid bell-shaped line where the mean and standard deviation are indicated in the box text. Figure 1(b) depicts an exponential utility function for this hypothetical firm mapped over the same distribution of outcomes. The risk aversion coefficient, c, of 0.025×10^{-6} is used for this example. Considering the actual distribution of outcomes and utilizing (1), the firm's certainty equivalent (C_x) is equal to \$28.4 million. Utilizing the same risk aversion coefficient and (2), the approximation technique results in a C_x value of \$26.8 million. Of course the closer the actual distribution is to the normal approximation, the more precise the estimation of the firm's risk aversion coefficient, c, in (2).

An Example Application

Our intent is to infer the firm's risk attitude by reconstructing the set of risky alternatives that were actually selected for resource allocations by the firm. The data available for this purpose do not provide detailed information on individual exploration opportunities, but do provide a basis for reconstructing typical projects that were selected by the firm, and the number of these projects that were selected. Although historical data are

[4] Exploration expense represents the amount of funds committed to an exploration project prior to the resolution of any uncertainty associated with the risky investment.

used in reconstructing these investment opportunities, we have used the means from several years of experience in some cases in order to reflect estimates of what decision makers might have *reasonably anticipated* from the investment decisions rather than using the actual outcomes associated with a given year. The latter would represent an ex post reconstruction of the lotteries, rather than the ex ante view that we seek.

In reconstructing the risks of the exploration projects based on archival data, there are two key estimates that are made. First, an estimate must be made of the *probability* a project is successful, leading to the discovery of a commercial field. Second, an estimate must be made of the *reserves that will be discovered* associated with a successful project. The data base[5] provides the actual "success rate" for exploration wells drilled in a particular year, and the addition to reserves for that year. However, the actual success rate for a year and the reserve additions that will result from successful projects are unknown ex ante to the firm. The firm does, however, have historical data on the success rates of exploration wells from previous years, and on the reserve additions that have been added as a result of previous successes. Therefore, we have assumed that the risk anticipated by a firm in a particular year is best approximated not by the actual results known ex post, but by means resulting from past periods of time.

For the estimate of the probability of success of exploration projects in a particular year, we use the mean of the actual success rates of the firm for the previous three years. This information would be known by the firm when the decisions for the exploration projects for the next year are made, and would seem to be a reasonable basis for the firm's assessment of the risks for these projects. While the use of three years data is arbitrary, we repeated the analysis with mean estimates calculated over longer time intervals, and determined that the results were not particularly sensitive to this choice.

Using similar reasoning, we used the mean reserve addition per successful project over the entire ten year period as the best estimate of the reserves that would be associated with a successful project. The choice of the overall mean was used because a lag of several years

[5] Source of data: *Oil & Gas Journal* Energy Database, 1991.

Figure 1(a)

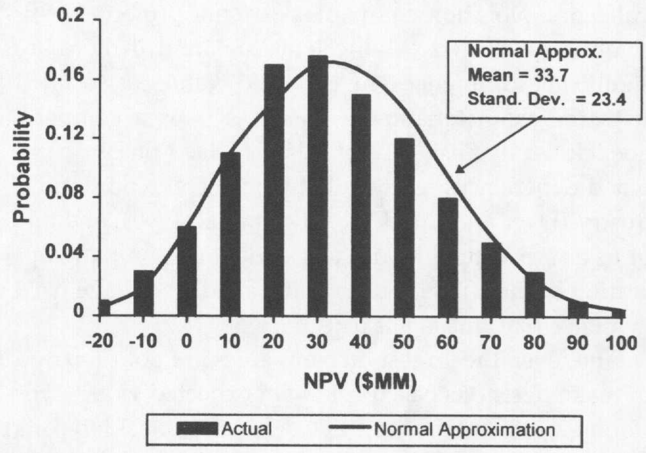
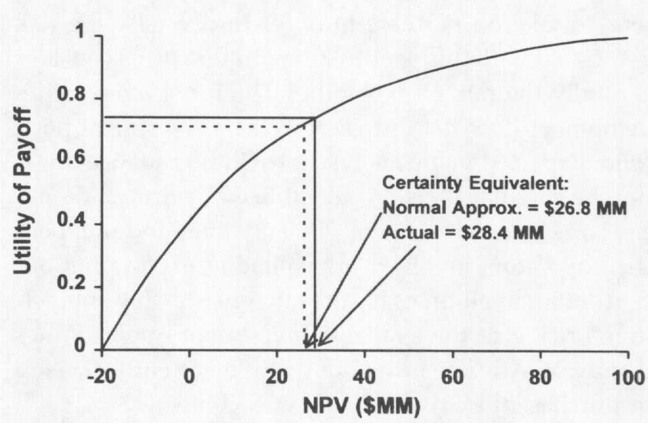


Figure 1(b) Exponential Utility Function $c = 0.025 \times 10^{-6}$



may occur between the time an exploration project is approved and the reserves associated with its successful completion are actually recognized by the firm. Therefore, it is impossible to link the reserve additions in any particular year to the exploration decisions in any specific previous year. This logic was applied separately to two categories of exploration projects for each firm, domestic and foreign.

As a result of this reconstruction process, the estimate of the risk propensity of each firm will be based on the typical exploration project considered in each year, rather than on the marginal project that represents the last one selected (or the first one rejected) from the list of potential projects. An argument could be made that the firm's risk attitude is revealed by the selection or rejection of these marginal projects rather than by the typical project that it selects. This argument would be valid if exploration companies do rank projects exclusively on expected value calculations and if there are significant differences in expected values associated with the characteristics of the projects as a company goes down its "list" of candidates. Based on our combined experiences as consultants to the exploration industry (Dyer and Lund 1982, Dyer et al. 1990), and one of us as a principal in an independent oil company operating in the United States and Canada, we have hard evidence that this is not true.

First, even the largest oil companies are not prepared to make decisions based solely on expected values. For example, when Standard Oil originally considered its participation in the North Slope venture, it had the highest expected value of any venture available to the firm at that time. However, Standard Oil was more than anxious to take on partners in order to diversify the risk associated with this venture. Exploration firms consider carefully the mix of exploration (high risk) versus development (low risk) projects in their investment portfolio. Expected value analysis provides guidance but is not the singular decision rule utilized by firms. Second, the large number of major oil companies and independent operators involved in evaluating exploration opportunities at all times ensures that reasonably competitive pricing of the available investment opportunities does exist. Any one firm's ability to consistently develop or purchase undervalued projects is unlikely.

As an example of our risk propensity calculation we examine the case of ARCO, a publicly held major integrated oil company, for the period 1983–1990. The data set and the calculated risk aversion coefficient c pertain only to the firm's exploration and production business unit. The statistical and archival data necessary to calculate the firm's risk aversion coefficient in the time periods of interest are itemized in Table 1.

Exploratory success rates (C and D in Table 1) are equal to the number of exploratory well successes divided by the number of exploratory wells drilled. Domestic and foreign reserve additions (G and H in Table 1) are based on the firm's reported new reserves added as a result of exploration activity. Net present value per barrel oil equivalent (BOE) represents a measure of the value of the period's reserve additions through a calculation where all costs are deducted from estimated future cash inflows from production discounted by 10% to produce a standardized measure per BOE. The adjusted domestic and foreign net present values for new reserve additions (L and M in Table 1) represent an approximation of the outcomes for the total domestic and foreign exploration programs for each period.

Since our model characterizes the annual exploration budget as the "buying price" for each lottery category, a constant equal to the value of the domestic and foreign exploration budgets (A and B in Table 1) is added back to each outcome associated with the lottery, items L and M, respectively. Adding the constant for each category to the "failure" outcome transforms that outcome to $0 in all cases.[6] Since we are interested in computing a distribution on individual investment outcomes, we calculate an adjusted NPV per exploratory well (N and O in Table 1) as the sum of the adjusted NPV's (L for domestic and M for foreign in Table 1) divided by the sum of exploratory wells for each category over the ten year period. This value is the simple mean for adjusted outcomes on a per well basis over the eight-year period and is representative of the firm's average per well outcome. Since the firm makes risky investment decisions based on multiyear exploration results, rather than on a single year's outcomes, it is reasonable to incorporate the entire period's prospect results as a part of the ex ante modeling procedure, as discussed above.

The domestic and foreign mean NPV's for ARCO (P and Q in Table 1) are calculated as the number of successes (np) times the eight-year average NPV/well (N and O in Table 1). The variance ($np(1-p)$) of the distribution is calculated similarly (see Table 1). The grand mean and total variance represent the sum of the means and variances for the domestic and foreign investment distributions, respectively. The certainty equivalent (C_x) for the overall annual lottery is equal to the sum of ARCO's leasehold/exploratory budget allocations for domestic and foreign investments (A and B in Table 1). Having defined all values in (2), except c, we now re-

[6] Addition of a constant to each payoff, equal to the domestic and foreign exploration budgets, allows for the characterization of the annual budgets as the certainty equivalent (buying price) of each lottery. In the special case of constant risk aversion, the risk premium is the same for all gambles that are identical except for adding the same constant to each payoff; also, under these conditions, the resulting implied risk-aversion coefficient, c, is unaffected by this transformation.

Table 1 Risk Aversion Coefficient (c) Calculation (ARCO 1983–1990)

(Except Item 1, All NPVs are in $MM)	1990	1989	1988	1987	1986	1985	1984	1983
A. Domestic Exploratory Budget ($MM)	483	384	323	232	341	785	996	849
B. Foreign Exploration Budget ($MM)	232	173	232	163	120	223	246	195
C. Domestic Success Rate	0.35	0.33	0.33	0.30	0.31	0.33	0.35	0.34
D. Foreign Success Rate	0.30	0.31	0.38	0.40	0.38	0.37	0.37	0.33
E. Domestic Exploratory Wells	75	66	70	47	56	152	156	106
F. Foreign Exploratory Wells	24	18	20	15	9	26	34	28
G. Domestic Res. Additions (MMBOE)	102	164	135	138	31	146	304	60
H. Foreign Res. Additions (MMBOE)	119	3	17	77	35	36	47	31
I. Domestic Foreign $NPV/BOE	5.88	5.41	4.60	3.72	7.59	6.04	6.26	15.36
J. Domestic NPV Additions [G × I]	600	887	621	513	235	882	1903	922
K. Foreign NPV Additions [H × I]	701	16	78	286	266	217	294	476
L. Adjusted Domestic NPV [J/C + A]	2209	3085	2224	1931	1094	3439	6412	3548
M. Adjusted Foreign NPV [K/D + B]	2599	225	437	879	829	822	1035	1635
N. Domestic 8-Yr. Average NPV/Well	—	—	—	32.9	—	—	—	—
O. Foreign 8-Yr. Average NPV/Well	—	—	—	48.6	—	—	—	—
P. Domestic Mean NPV[C × E × N]	857	710	753	466	570	1664	1805	1196
Q. Foreign Mean NPV [D × F × O]	345	275	371	293	0	463	614	448
R. Domestic Variance $[((E(1-C)C)^{1/2})N]^2$	18×10^6	16×10^6	17×10^6	11×10^6	13×10^6	36×10^6	38×10^6	26×10^6
S. Foreign Variance $[((E(1-D)D)^{1/2})O]^2$	12×10^6	9×10^6	11×10^6	9×10^6	0	14×10^6	19×10^6	15×10^6
T. Grand Mean [P + Q] ($MM)	1203	985	1123	759	570	2127	2420	1644
U. Total variance [R + S] ($MM)	30×10^6	25×10^6	28×10^6	20×10^6	13×10^6	51×10^6	57×10^6	41×10^6
V. Total CEQ[A + B] ($MM)	715	557	555	395	341	1008	1242	1044
W. Risk-Aversion Coeffic. ($c \times 10^{-6}$)	0.032	0.034	0.041	0.038	0.035	0.044	0.041	0.030
X. Risk Tolerance ($1/c$) ($MM)	31.0	29.0	24.5	26.4	28.3	22.7	24.3	33.7

arrange the equation and solve for the *implied risk aversion coefficient* c for each of the eight year study periods (highlighted area on Table 1). ARCO exploration and production business unit's implied *risk tolerance* $(1/c)$ for each of the study periods is indicated on Table 1 (item X).

4. Results

This ex ante risk propensity model was applied to a sample of 55 petroleum exploration firms during the period 1983 through 1990, estimating a year by year implied utility function for the firms' E&P business units. Regarding the propositions in §2, regression and statistical results are presented with respect to across and within firm analyses. Findings discussed include the relationships between: (1) firm size and corporate risk tolerance; (2) changes in firm size and changes in corporate risk tolerance; and (3) corporate risk tolerance and firm performance.

Risk Tolerance

In Proposition 1 we propose that corporate risk taking behavior is characterized by a risk-averse utility function. To test Proposition 1 we examine the computed risk-aversion coefficient c in the exponential utility function for each firm in each period of the sample. A positive c implies a concave utility function or risk-averse decision behavior; a negative c implies a convex utility function or risk seeking behavior. Of the 329 calculated c coefficients for the sample of firms, 324 are positive and five are negative. This finding provides strong support for Proposition 1. Table 2 provides a summary of risk tolerance (RT) levels, $1/c$, for each of the largest 25 E&P firms over this eight year period. Size ranking is based on 1990 total exploration and production assets. Of the 186 risk-aversion coefficients for this group, 183 were positive and three were negative (incomplete data for certain years reduced total observations from 200 to 186). These results are compelling, given the fact that the total E&P assets of each year's top 25 firms represent

Table 2 Risk Tolerance Level (1/c) 1983–1990; Top 25 Companies (Based on 1990 Total E & P Assets)

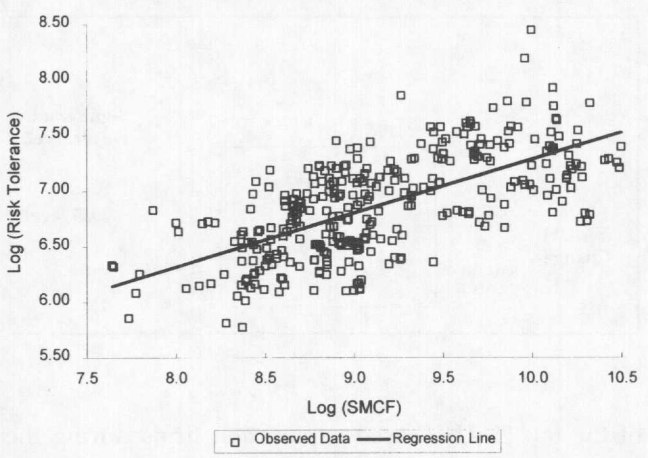
($ Millions)

	1990	1989	1988	1987	1986	1985	1984	1983	1990 E&P Assets ($ Millions)
Exxon	24.9	18.9	20.8	16.5	16.8	16.1	18.0	19.4	69,781
Chevron	17.4	23.8	16.9	11.5	11.3	13.8	10.7	156.5	29,193
Texaco	22.7	281.3	10.9	12.0	12.4	10.2	15.7	10.2	19,710
Mobil	61.6	13.0	12.8	8.0	6.4	5.4	6.1	6.3	17,218
Amoco	5.3	12.9	25.2	17.5	9.1	13.3	35.2	26.5	16,977
Shell Oil	85.4	62.7	64.4	37.5	34.3	43.4	44.8	58.1	14,585
USX Corp., O&G Unit	8.6	6.5	6.7	6.4	6.2	4.7	7.6	10.2	11,332
ARCO	31.0	29.0	24.5	26.4	28.3	22.7	24.3	33.7	11,146
Amerada Hess	497.8	21.6	8.9	7.3	9.1	11.9	11.8	19.3	9,057
Conoco	55.7	40.8	37.7	37.8	33.8	37.3	38.0	40.0	6,732
Oryx Energy	29.3	18.4	12.8	10.0	−10.7	N/A	N/A	N/A	5,252
Unocal	38.2	25.8	21.4	20.2	N/A	N/A	N/A	N/A	4,852
Occidental Petroleum	32.5	29.4	26.5	23.7	19.6	25.6	26.1	42.4	4,813
Phillips Petroleum	18.4	21.0	34.1	27.4	21.4	19.1	19.8	22.6	4,277
Burlington Resources	2.3	7.4	3.6	3.0	3.4	4.0	3.7	2.2	3,441
Consolidated Nat. Gas	1.3	1.3	1.3	5.9	8.9	5.5	4.8	6.6	2,899
Union Pacific Resources	15.5	15.2	−6.2	N/A	15.9	13.0	19.2	19.6	1,880
Anadarko Petroleum	12.8	8.0	7.4	7.1	9.2	8.6	12.2	N/A	1,647
Union Texas Petroleum	10.6	13.2	12.1	10.9	14.3	9.6	12.3	72.5	1,554
Freeport McMoRan	5.6	4.2	5.0	N/A	8.9	11.8	23.7	11.6	1,547
Kerr-McGee	13.2	19.5	N/A	8.9	12.0	27.6	5.3	N/A	1,426
Enron	1.5	1.3	1.9	1.5	1.6	5.3	2.5	3.2	1,379
Pennzoil	4.5	2.8	8.3	−5.8	N/A	2.5	2.5	2.4	1,342
Enserch	N/A	N/A	16.5	15.2	16.9	15.9	14.7	13.0	1,246
Maxus Energy	N/A	N/A	9.4	16.6	17.0	11.7	10.0	18.7	1,158

an average of 88% of the total assets for the group of 55 firms studied.

Relationship Between Risk Tolerance and Firm Size
To test Proposition 2, we propose a model that describes the relationship between firm size and ex ante corporate risk tolerance. For oil companies, an appropriate measure of firm size is the *Standardized Measure of Discounted Future Net Cash Flows* (SMCF). This figure represents a measure of the value of the firm's oil and gas reserves through a calculation where future production and development costs and income taxes are subtracted from future cash inflows from production. The result is then discounted by 10% for the timing of estimated cash flows to produce the standardized measure of discounted future net worth. The SMCF measure is the same whether full cost or successful efforts accounting is used and is a required computation for 10-K filings. In effect, this measure represents the "wealth" of the oil and gas exploration business unit. Howard (1988) has suggested that among firms in the same industry, there exists an approximate linear relationship between corporate *risk tolerance* and certain financial measures of the firm, i.e., sales, net income, equity. Howard defines the risk tolerance ratio as the ratio of *risk tolerance* to these observed financial measures. This measure is intuitively appealing. There are firms in the present study's sample set, however, with SMCF values which vary from $7.0 *million* to $35 *billion*. Given the minimum amount of capital (or minimum *risk tolerance*) required to compete in this industry, even on a small basis, it is unlikely that a firm with a $35 billion SMCF value will have a *risk tolerance* which is 5000 times greater than the firm with a $7.0 million SMCF value. This example suggests that

Figure 2 **Log(RT) vs. Log(SMCF); Year 1983–1990**



the relationship may be better explained by a model where RT increases with SMCF but at a decreasing rate. We utilize a modified version of Howard's risk tolerance ratio to more appropriately account for the relationship between firm size and corporate *risk tolerance* in any given time period. The model to be tested is:

$$a = \mathrm{RT}/\mathrm{SMCF}^b, \quad (3)$$

where according to Proposition 2, we expect b to be positive and less than 1.0.

To test the relationship in Equation (3), we take the log of each side of and rearrange to set the equation equal to the dependent variable, RT. The model tested for Proposition 2 for each time period of interest then becomes:

$$\mathrm{Log}(\mathrm{RT}_{it}) = a - b\,\mathrm{Log}(\mathrm{SMCF}_{it}) + e, \quad (4)$$

where i is an index for the firm and t for the year. Inputs to the model include data for each of the 55 firms and for eight annual periods of investigation, 1983 through 1990.

Analysis confirms that across firms there exists a statistically significant positive relationship between firm size and risk tolerance. With an R^2 of 0.44, nearly half the variance associated with the firm's ex ante corporate risk taking behavior is explained by firm size. Figure 2 shows a plot of Log(SMCF) versus Log(RT), with the observed values and regression line.

Proposition 2 is also supported by the year-by-year analysis of the relationship between firm size and risk tolerance. Table 3 summarizes the important statistical parameters. Except 1984, the findings indicate a 0.001 significance level for the hypothesized positive relationship between firm size and risk tolerance. *What emerges from this analysis is that consistently across firms, there exists a positive relationship between corporate risk tolerance and the size of the firm*. These findings are also consistent with Howard's (1988) argument that the ratio of corporate risk tolerance to certain financial measures is equal to a constant. *Our findings extend Howard's work by suggesting the relationship between risk tolerance and size may be better explained by a model where RT increases with size but at a decreasing rate.*

Changes in Risk Propensity

In Proposition 3 we hypothesize that within-firm changes in RT and changes in SMCF are dependent qualitative variables and positively related. We utilize the *chi-square* statistic to assess dependence between these variables. Based on the observed and expected frequencies for each combination of variables, the *chi-square statistic* ($\chi^2 = 4.16$) suggests that changes in RT and changes in SMCF are statistically dependent variables. In our second test, we utilize a nonparametric statistical test of differences, the *sign test*, to capture the *within* firm changes in size as well as risk tolerance over the period of interest. The sign test does not consider the absolute size of differences between the sample pairs but only the direction of those differences. For each time period we distinguish between those firms which grew in size, where $\mathrm{SMCF}_{t+1} > \mathrm{SMCF}_t$, and those firms which diminish in size, where $\mathrm{SMCF}_{t+1} < \mathrm{SMCF}_t$. We also distinguish between those firms which became more risk tolerant, where $\mathrm{RT}_{t+1} > \mathrm{RT}_t$, and those firms which became more risk averse, $\mathrm{RT}_{t+1} < \mathrm{RT}_t$, from

Table 3 **Descriptive Statistics for Size (SMCF) and Risk Tolerance (RT)**

Period	Intercept	Coefficient	Observations	R^2	Significance
1983–1990	2.443	0.484	324	0.44	0.001
1990	1.838	0.549	41	0.49	0.001
1989	0.928	0.651	41	0.54	0.001
1988	1.872	0.548	42	0.52	0.001
1987	1.874	0.542	35	0.47	0.001
1986	2.488	0.477	39	0.43	0.001
1985	3.819	0.332	43	0.32	0.025
1984	3.658	0.353	45	0.37	0.001
1983	2.044	0.529	38	0.44	0.001

period to period. Over the seven change periods there are a total of 260 data points. Figure 3 depicts a two-by-two matrix summarizing the hypothesized relationships between changes in corporate risk tolerance and firm size.

The nonparametric statistical sign test indicates only partial support for Proposition 3. In the case of firm growth ($SMCF_{t+1} > SMCF_t$), increases in risk tolerance ($RT_{t+1} > RT_t$) are associated with increases in firm size; this finding is statistically significant at the 0.025 level. However, during periods of size reduction ($SMCF_{t+1} < SMCF_t$), there exists no statistical relationship between changes in firm size and changes in corporate risk tolerance.

Partial support of Proposition 3 is consistent with earlier arguments that as the firm grows and accumulates additional wealth, its ability to take on larger, more risky projects also grows. This finding also partially supports the notion that on a "within-firm" basis, the property of decreasing risk aversion is representative. Support for this argument is mitigated somewhat by the fact that decreases in firm size are not necessarily associated with decreases in corporate risk tolerance. This phenomenon may be partially explained by Bowman's (1982) finding that troubled companies become "risk-seeking" in the domain of losses. This explanation would assume that firms in the present study which have decreased in size ($SMCF_{t+1} < SMCF_t$) are "troubled" or nonperforming firms.

Figure 3 **Risk Tolerance Change**

		+ $RT_{t+1} > RT_t$	- $RT_{t+1} < RT_t$		Significant Difference?
Size (SMCF) Change	+ $SMCF_{t+1} > SMCF_t$	94	55	n = 149	yes .0025 level
	- $SMCF_{t+1} < SMCF_t$	55	56	n = 111	no

Risk Tolerance Ratio (RTR)

We develop a *new*, normalized measure of risk taking which allows for across-firm analysis of risk propensity. This measure, the *risk tolerance ratio* (RTR_i), is designed to control for firm size. The RTR_i value is equal to RT_i/RT_i', where RT_i is the observed risk tolerance for firm i in period t and RT_i' represents the predicted risk tolerance (as defined by the intercepts and regression coefficients in Table 3) of firm i as a function of size ($SMCF_i$) for that same period t. This measure describes the firm's *relative* risk propensity as compared to the sample of firms in the industry during the period of investigation. An RTR value greater than 1.0 implies a stronger propensity to take risk than firms of equivalent size within the sample set. An RTR value less than 1.0 implies a weaker propensity to take risk than firms of equivalent size. Table 4 presents the RTR values for each of the top 25 U.S.-based exploration firms during the eight-year period from 1983–1990. As an example, let us compare the relative risk propensities of Exxon (RTR = 0.71) and Shell Oil (RTR = 3.39) for the year 1988. This measure implies that Exxon, given its total SMCF value, was less willing to take risk than firms of its equivalent size; conversely, Shell Oil could be characterized as an aggressive risk taker compared to other firms in the industry that had similar SMCF values.

Ex ante Risk-Ex Post Return Relationship

Ex post return is measured in terms of return on total exploration and production assets (ROA). For purposes of return calculation, income is defined as earnings before interest but after taxes. The RTR and return measure are lagged one year (example: 1983 RTR vs. 1984 ROA). Two different methodologies are employed to test the relationship between RTR and ex post return (Proposition 4). The first is a nonlinear regression model relating ROA to RTR as follows:

$$ROA = 2.75 + 6.87RTR - 1.91RTR^2. \qquad (5)$$

A plot of the observed values and the fitted nonlinear regression model is shown in Figure 4. Statistical analysis indicates an adjusted R^2 for this regression of 0.11. The regression coefficients, b_1 and b_2 are statistically significant at the 0.001 level.

Because the nonlinear relationship identified in Equation (5) reaches a maximum between the endpoints of the RTR range, we analyzed this relationship between ROA and RTR in more detail using a second statistical methodology, analysis of variance (ANOVA). We distinguish among firm risk propensity by using four categories of risk tolerance. Those categories are defined

Table 4 Risk Tolerance Ratio (RTR) 1983–1990 Top 25 Companies (Based on 1990 Total E&P Assets)

Company	1990	1989	1988	1987	1986	1985	1984	1983
Exxon	0.62	0.37	0.71	0.59	0.73	0.80	0.79	0.53
Chevron	0.60	0.73	0.75	0.59	0.65	0.86	0.58	7.60
Texaco	0.93	10.25	0.56	0.69	0.72	0.67	0.85	0.47
Mobil	1.92	0.36	0.50	0.33	0.31	0.31	0.30	0.20
Amoco	0.18	0.35	0.99	0.80	0.46	0.78	1.85	0.90
Shell Oil	3.46	2.39	3.39	2.10	2.19	2.83	2.60	2.32
USX Corp., O&G Unit	0.54	0.40	0.50	0.53	0.51	0.38	0.56	0.66
ARCO	1.20	1.03	1.32	1.57	1.93	1.55	1.43	1.33
Amerada Hes	35.73	1.66	0.93	0.88	1.06	1.28	1.17	1.66
Conoco	3.45	2.59	3.20	3.90	3.42	3.57	3.19	2.82
Oryx Energy	1.97	1.34	1.15	1.04	1.16	N/A	N/A	N/A
Unocal	2.08	1.34	1.44	1.50	N/A	N/A	N/A	N/A
Occidental Petroleum	2.47	2.22	2.58	2.40	1.94	2.41	2.14	2.98
Phillips Petroleum	1.16	1.24	2.58	2.60	2.03	1.78	1.58	1.55
Burlington Resources	0.22	0.74	0.43	0.51	0.55	0.50	0.48	0.27
Consolidated Nat. Gas	0.21	0.21	0.21	1.16	1.62	0.87	0.77	1.24
Union Pacific Resources	1.94	1.86	N/A	N/A	2.43	1.62	2.16	2.03
Anadarko Petroleum	2.04	1.23	1.13	1.31	1.53	1.46	1.88	N/A
Union Texas Petroleum	1.15	1.74	1.78	1.66	2.21	1.20	1.50	8.21
Freeport McMoRan	0.85	0.61	0.69	N/A	1.34	1.81	3.53	2.37
Kerr-McGee	1.83	3.09	N/A	1.97	2.26	4.00	0.86	N/A
Enron	0.24	0.21	0.33	0.25	0.25	0.76	0.30	0.53
Pennzoil	0.55	0.40	1.18	N/A	N/A	0.32	0.31	0.28
Enserch	N/A	N/A	3.30	3.30	3.47	2.68	2.24	2.41
Maxus Energy	N/A	N/A	1.36	3.15	2.96	1.69	1.25	2.25

along the dimension of RTR and are shown in Table 5, which also summarizes the ROA statistical information for the set of firms within these risk tolerance categories. We observe the highest mean ROA in the Moderate RTR category. To investigate the relationship between the category of risk tolerance and return on E&P assets, Proposition 4A is tested.

PROPOSITION 4A. *The mean return on E&P assets for firms with Moderate Risk Tolerance (RTR between*

Figure 4 RTR vs. ROA (1983–1990; One-year Data Lag)

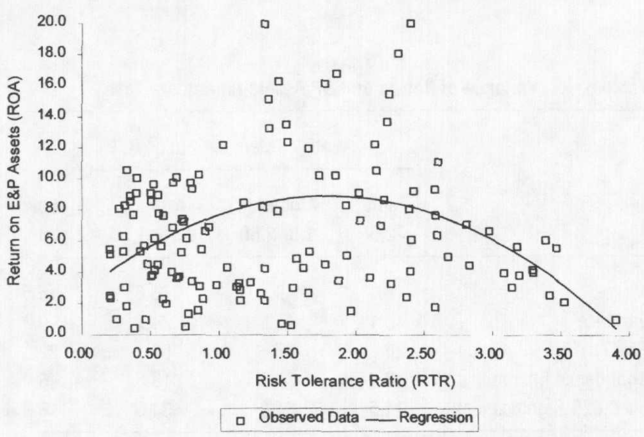


Table 5 Return on E&P Assets—ROA (%) Summary Data—ANOVA

	Risk Tolerance Ratio (RTR)			
	High >2.50	Moderate 1.5–2.50	Average 0.5–1.50	Low <0.50
Maximum	11.1	28.1	28.7	10.6
Minimum	1.0	0.6	0.5	0.4
Mean	5.0	9.1	5.7	5.3
Variance	6.1	40.3	24.7	9.3
Standard Deviation	2.5	6.4	5.0	3.1
Size (n)	20	37	56	22
Confidence Interval	6.9	10.7	7.7	7.2
(@ 0.025 Significance)	3.3	8.1	5.6	3.8

1.50–2.50) *is greater than firms with Low Risk Tolerance (RTR's* < 0.50), *firms with Average Risk Tolerance (RTR between* 0.50–1.50), *and firms with High Risk Tolerance (RTR* > 2.50).

The analysis of variance (ANOVA) test statistic, F, is equal to 4.79; this finding suggests there are statistically significant (0.025 level) differences in the mean ROAs associated with these categories. In a two-way comparison between categories, there exist no overlaps between confidence intervals; the mean ROA for the Moderate Risk Tolerance (RTR = 1.50–2.50) category clearly differs from the High Risk Category (RTR > 2.50), the Average Risk Category (RTR = 0.50–1.50) and the Low Risk Category (RTR < 0.50). This finding supports Proposition 4A.

Both methodologies utilized in the ex ante risk/ex post return investigation provide support for Proposition 4. *With regard to achieving higher return on assets, these data indicate there exists an optimal range of corporate risk tolerance. E&P firms categorized with Moderate Risk Tolerance levels (implied RTR of* 1.50 *to* 2.50) *demonstrate significantly higher returns than those firms either more or less risk tolerant.*

Our finding that the Moderate Risk Tolerance Category is associated with higher returns over the eight-year study period suggests that on average, firms or SBUs in the petroleum exploration industry have been too cautious with respect to risk. Firms which are willing to implement risk policies which are characterized by RTR values one and a half to two and a half times greater than what the average equivalently sized firms implement, are more likely to achieve superior returns. For those firms in the Average and Low Risk Tolerance Categories, this would suggest that they have overestimated their probability of bankruptcy or financial distress, and in so doing have traded off excess expected profit maximization. The resulting effect is the selection of a sub-optimal risk tolerance level and less than superior asset returns. Firms in the High Risk Tolerance Category have been excessively risk-seeking, given their financial strength. One possible explanation for their low returns is that the credit/capital markets have interpreted their investment policies as "hazardous"—a condition which leads to increased cost of funds, making once viable projects uneconomic. Other explanations may be: (1) that firms who may be characterized as in the "loss" domain, relative to their industry, become risk seeking; or (2) that in making strategic investment decisions, firms included within this low performing group, adjust for risk ad hoc, if at all. Failure to account for risk adequately may lead to inappropriate decisions.

Ex Ante Risk-Ex Post Risk Relationships

To test Proposition 5, which hypothesizes a positive relationship between ex ante risk and ex post risk, we make an estimate of the population variance for each risk propensity (RTR) category. This across-firm analysis utilizes data pooled across firms and time periods where *variance* on after-tax E&P asset returns (ROA) is the measure of interest. That is, firms may move from one *risk tolerance* category to another over the study period. This analysis is on a risk tolerance category or group basis rather than a firm-level basis. Variance of ROA was computed for an RTR category as the arithmetic mean of the individually squared deviations of each observed value from the RTR category mean. Utilizing a *chi-square* statistic, confidence interval estimates for each category were calculated. Table 6 shows the results of this statistical analysis. Examination of the confidence interval estimates for each category of risk tolerance confirms the rejection of Proposition 5 at the 0.05 significance level.

Statistically significant differences in variance exist between several categories in Table 6; however, these differences are not consistent with the hypothesized relationship in Proposition 5. Ex ante *risk propensity is not positively associated with the ex post risk measure, variance.* The ex post variance measure possesses a general positive relationship with ex ante risk tolerance across the

Table 6 Variance of Return on E&P Assets Chi-square Test

	Risk Tolerance Ratio (RTR)			
	High >2.50	Moderate 1.5–2.50	Average 0.50–1.50	Low <0.50
Mean	5.1	9.4	6.6	5.5
Variance	6.1	40.3	24.7	9.3
Size (n)	20	37	56	22
Confidence Interval	3.9	26.0	18.5	6.0
(@ 0.025 Significance)	11.5	54.8	34.6	16.9

Low Risk, Average Risk and Moderate Risk Categories.[7] However, Proposition 5 is rejected given the low *variance* (6.1%) associated with the High Risk Category. In fact, the variance of E&P asset returns associated with the High Risk Category represents the lowest ex post risk measure of all ex ante RTR categories.

Explanations for this finding may be consistent with some arguments in the literature that *variance* is an inadequate construct for conceptualizing risk (Ruefli 1990 and 1991). Given the low mean return of firms in the High Risk Category, low variance of returns may be the result of these firms being consistently poor performers. The variance measure only characterizes the symmetric dispersion about the mean performance. In this case, firms implementing a strategy characterized by the High Risk Category on average had a low return on assets and there was little variability in the returns across firms in this category.

We also used the *ordinal* risk measure[8] to test for differences in ex post risk among *risk tolerance* categories. *Ordinal risk* is an alternative measure of risk which directly addresses the issue of gains and losses and allows researchers to establish risk in a strategic context. An intuitive feel for this ordinal measure can be obtained by considering that our set of competing oil companies are ranked against each other annually on the basis of return on E&P assets. Favorable events are those that yield an improvement in rank, while unfavorable events are those that result in a loss of rank. That component of ordinal risk in which we are interested in this study is defined in terms of a loss in strategic position along the dimension of return on E&P assets. This entropy-based measure is concerned with a firm's relative position within the system; therefore, for our purposes it is necessary to assign each firm in the study to a specific *risk tolerance* category.

Designation of a firm to a *risk tolerance* category was based on the firm's most frequently occurring risk tolerance category over the eight year study period. Table 7 summarizes the *ordinal* risk analysis statistic by RTR category. In essence, the ordinal statistic for a given category represents its portion of the total strategic risk of the system, which is the sum of the ordinal risk across all categories.

Differences in the *ordinal* risk measure across categories again suggest that Proposition 5 should be *rejected* at the 1% significance level. However, the pattern of relationships between ex ante risk tolerance and the alternative measures of ex post risk, *ordinal* and *variance*, are substantially different. *In the ordinal analysis, high returns are associated with low ex post risk.* The Moderate Risk Category, characterized by superior returns on E&P assets, possesses the lowest *ordinal* risk. This negative relationship between risk and return, commonly referred to as the "Bowman paradox" (Bowman 1982), is consistent with other risk-return studies in the strategic management literature (Bettis 1981, Bettis and Hall 1982). Notwithstanding the differences in findings between *variance* and *ordinal* risk, both measures reject the notion of a strict positive relationship between ex ante and ex post risk as posited in Proposition 5.

5. Implications and Discussion

This study introduces a measure of ex ante risk that conforms more closely to the manner in which managers conceptualize the notion of risk. By differentiating between the concepts of ex ante risk (*risk tolerance*) and ex post risk (*variance* and *ordinal* measures), this work separately analyzes the information embedded in each of these distinct measures. The important implication is that we are able to make stronger inferences about

Table 7 Ordinal Risk Measure Results of Statistical Analysis

	Risk Tolerance Ratio (RTR)			
	High >2.50	Moderate 1.5–2.50	Average 0.50–1.50	Low <0.50
Mean	5.1	9.4	6.6	5.5
Ordinal Risk	0.0130	0.0058	0.00837	0.0062
Size (n)	30	24	72	24
Confidence Interval	0.0143	0.0072	0.0092	0.0077
(@ 0.025 Significance)	0.0117	0.0044	0.0075	0.0048

F Statistic 16.67—Statistically Significant at the 0.001 Level.

[7] This positive relationship is less than robust given the lack of statistical significance between the Moderate Risk and Average Risk Categories. However, differences do exist between these categories along the *variance* dimension.

[8] See Ruefli and Wilson (1987), Ruefli (1990), and Collins (1991) for the mathematical derivation and measurement mechanics associated with the *ordinal* risk measure.

causal relationships among temporally ordered variables (ex ante risk and performance), thus understanding more clearly the effects of risk selection behavior by the firm. A limitation of this study may be that it would be difficult to reproduce in other industry segments where detailed information regarding investment decisions is not publicly available.

This study substantiates, in the across-firm analysis, economists' long held assumption that the degree of risk aversion decreases as wealth increases. Our findings also suggest that in the petroleum industry corporate risk-taking behavior affects firm performance. This result has prescriptive implications in terms of how managers should set corporate risk policy. Findings relating to *changes* in corporate risk tolerance have special relevance to researchers interested in business risk management. Our findings imply that increases in *risk tolerance* are associated with increases in firm size; however, during periods of size reduction, there appears to be no statistical relationship between change in size and change in corporate risk tolerance. The consequences associated with the latter phenomenon may indeed have an impact on firm performance and deserve further investigation.

Strategic investment choices affect ex post risk as well as return. This study uncovers substantial differences in the traditional ex post measure of risk, *variance*, and the alternative *ordinal* risk measure. In addition, there appear to be specific differences in the information embedded in ex ante and ex post risk measures. In fact, this study rejects the notion of a high correlation between ex ante and ex post measures of risk. These findings suggest that equating the firm's risk selection behavior with any ex post measure of risk may be capricious.

Our findings support earlier arguments that *variance* tells us little about the riskiness of a specific decision strategy, but only provides information about the relative dispersion about some mean. In contrast, the *ordinal* risk measure provides an intuitive and meaningful conceptualization of risk, by measuring the firm's chance of relative position loss, or downside uncertainty, among a group of competitors. In the *variance* analysis, high returns are associated with *high ex post "risk"*; in contrast, in the *ordinal* analysis, high returns are associated with *low ex post risk*. This finding has implications for researchers studying risk-return relationships. The *variance* analysis is not consistent with what is commonly referred to as "Bowman's paradox" (Bowman 1980); however, the *ordinal* analysis strongly supports the notion of a negative risk-return relationship. *The broader implication is that ex post risk measures are significantly affected by corporate risk taking. More importantly, from an ordinal risk perspective, there may exist an optimal strategy of risk taking which leads to high returns and low ex post risk.*

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