Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Petroleum Science and Engineering 48 (2005) 127–140

Journal of Petroleum Science & Engineering

www.elsevier.com/locate/petrol

Corporate risk-taking and performance: A 20 year look at the petroleum industry

Michael R. Walls*

Division of Economics and Business, Colorado School of Mines, United States

Received 1 February 2005; received in revised form 19 June 2005; accepted 20 June 2005

Abstract

This empirical study of the petroleum E&P sector investigates the financial risk tolerance of the 50 largest U. S.-based firms during the period 1981–2002. A decision analysis model is utilized to measure the financial risk tolerance of each firm for each year during the study period. Relationships between firm size and risk tolerance as well as foreign versus domestic risk propensity are analyzed. In addition, firms are compared in terms of their relative risk-taking by controlling for firm size. Finally, we present some other interesting statistical results that relate risk tolerance to performance. Firms in the high risk tolerance category perform significantly better than firms less willing to take financial risk. Implications from these findings are discussed in terms of E&P risk management and decision making.

Keywords: Risk management; Uncertainty; Exploration; Decision analysis

1. Introduction

Risk and risk management are fundamental elements of the E&P competitive landscape. Managing petroleum risk is a complex and essential task, with both immediate and lasting effects on firm performance. The primary motivation for this study is to better understand the implications of different levels of risk-taking behavior by E&P companies. The empirical framework described in this paper provides a better understanding of the implications of risk-taking behavior by E&P firms and also has prescriptive implications with regard to setting corporate risk policies.

This study provides an up-to-date look at the risk-propensities of the 50 largest US-based oil companies. It utilizes a previously developed decision analysis framework to evaluate the capital allocation decisions of these firms and their resulting financial risk tolerances. Results are provided for the top 23 US-based oil companies for the period 1983–2002. The study examines both domestic and foreign risk tolerances and explores the differences in risk tolerances among these firms. In addition, we utilize the risk tolerance ratio (RTR) measure as a means to examine the rela-

* Tel.: +1 303 273 3492.
E-mail address: mwalls@mines.edu.

0920-4105/$ - see front matter
doi:10.1016/j.petrol.2005.06.009

tive risk propensity of firms, thereby controlling for firm size. Finally, results are provided with regard to the relationship between risk-taking and performance over the 20 year study period.

The findings have broad implications for managers who are trying to best allocate corporate resources. First, a company's E&P risk policy affects its business unit performance. Second, risk management models enable decision makers to implement their desired and appropriate risk tolerance level in all types of project analyses. Third, knowledge of competitors' risk preferences may help managers make better decisions in a competitive setting. Lastly, quantifying a firm's financial risk tolerance provides a mechanism for managers to communicate and act upon an explicit and coherent risk policy — a policy that can lead to improved performance.

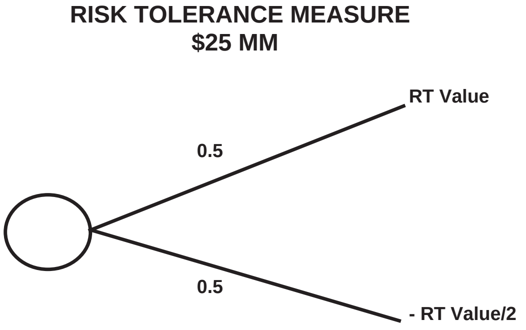
2. Modeling corporate risk tolerance

Preference analysis or expected utility theory provides a basis for constructing a utility function. Assessing utility functions for individuals provides a mechanism for representing preferences that incorporates risk attitudes. Expected utility analysis methodologies such as the 50–50 gamble assessment (Holloway, 1979) and the certainty equivalent approach (Clemen, 2001) are utilized to measure individual risk preferences. The technique utilized in this study draws on these same methodological approaches but extends the techniques in a way that enables their application in a corporate setting, whereby we are attempting to elicit the manager's risk preferences as an agent for the firm.

The utility function provides the manager guidance with regard to making choices under uncertainty. 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 a previous study by Walls and Dyer (1996) E&P firms' prior decisions regarding risky investments are the basis for inferring the risk attitude of the firm or business unit. Managers, as agents for the firm, make capital allocation decisions under conditions of risk and uncertainty and have knowledge concerning the magnitudes of potential outcomes and the probabilities associated with those outcomes. These decisions reflect the risk attitude of the firm and under certain conditions can be codified into the parameters of a von Neumann–Morgenstern utility function (Luce and Raiffa, 1957; Spetzler, 1968).

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 analysis and finance is the *exponential utility function*, and is of the form $u(x) = -e^{-x/R}$, where R is the *risk tolerance coefficient*, x is the variable of interest (generally net present value), and e is the exponential constant. A value of R less than infinity and greater than 0 implies risk averse behavior. The exponential form of utility can satisfactorily treat a wide range of corporate risk preferences.

The risk tolerance measure, R, in the exponential utility function is an important parameter as it describes the willingness of the firm to take on risky investments. More formally, the *risk tolerance measure represents the sum of money such that the decision makers are indifferent as a company investment to a 50–50 chance of winning that sum and losing half of that sum.* Risk tolerance is more complex than simply a sum of money that the firm is willing to put "at risk". The intuitive notion of risk involves both uncertainty and the magnitudes of the dollar values involved. The central issue associated with measuring corporate risk tolerance is one of assessing tradeoffs between potential upside gains versus downside losses under uncertainty. The decision maker's attitude about the magnitude of capital being exposed to the chance of loss is an important component of this analysis. Fig. 1 provides additional meaning to the notion of risk tolerance in terms of decisions about risky investments. Consider, for example, that a decision maker is presented three lotteries with a 50–50 chance of winning a certain sum and losing half that sum. The decision to reject Lottery #3 which has an even chance of winning \$30MM versus losing \$15MM implies that the decision maker would view this investment as too risky. Conversely, the firm's decision to accept Lottery #1 implies that the risk–return tradeoff associated with this lottery is acceptable, given the firm's willingness to take



Lottery	RT Value	- RT Value/2	Decision
#1	$20 MM	- $10 MM	Accept
#2	$25 MM	- $12.5 MM	***Indifferent***
#3	$30 MM	- $15 MM	Reject

Fig. 1. The risk tolerance measure, RT, represents that sum of money such that the firm is indifferent between a 50–50 chance of winning that sum and losing half that sum.

financial risk. This iterative procedure is continued until we identify the lottery such that the firm is *indifferent* between a 50–50 chance of winning a certain sum versus losing half that sum. In our example, that sum is $25MM and represents the risk tolerance of the firm.

Relating the risk preferences of the firm to decisions about risky investments, such as in Fig. 1, provides a more meaningful interpretation of the firm's risk propensity. In addition, it is reasonably easy to measure and serves as a sufficiently close approximation to the exponential risk tolerance, such that in this case, we are able compute the firm's risk tolerance as approximately $25 million. The concept of a corporate risk tolerance is foundational to the empirical study and results presented in this paper. The financial risk tolerances of firms included in this study are examined and the relationship between that risk tolerance and performance is investigated.

Another term of importance from preference theory is the valuation measure known as the *certainty equivalent*. The certainty equivalent is defined as that certain value for an uncertain event which a decision maker is just willing to accept in lieu of the gamble represented by the event (Holloway, 1979). It is, in essence, the ''cash value'' that a firm attributes to a decision alternative which involves uncertain outcomes. 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 maximum *buying price* or minimum selling price for a given risky investment represents its certainty equivalent for that risky investment. For discrete probability distributions, the formula for the certainty equivalent is:

$$C_x = -R\ln\left(\sum_{i=1}^{n} p_i e^{-x/R}\right) \quad (1)$$

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). In effect, if we know the characteristics of the risky investment alternative, as defined by p_i and x_i, and we know the amount of money the firm was willing to pay to participate in that risky investment, C_x, then we can infer the firm's risk tolerance, R. In the earlier example of risk tolerance described in Fig. 1, the certainty equivalent of lottery 1 is some positive number, the certainty equivalent for lottery 3 is negative, while the certainty equivalent of lottery 2 is 0, since the decision maker was indifferent.

3. Measuring E&P risk tolerance

Consider the simple case where the firm chooses to invest in one domestic project and one foreign project with probability and outcome information for each project as shown in Fig. 2a. Assume these investment opportunities have estimates of 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 as shown in Fig. 2b.

Now suppose that the firm's allocation for exploration expense (buying price) for each investment category, domestic and foreign, is known. We interpret these allocations as the certainty equivalent, C_x, for each individual lottery, that is, their buying price to participate in these investments. For example, let's assume that the C_x values are $2.2 million and $1.0 million for the domestic and international projects, respectively. The C_x value for the domestic investment implies, for example, that the firm is indifferent between a certain value of $2.2 million and an uncer-

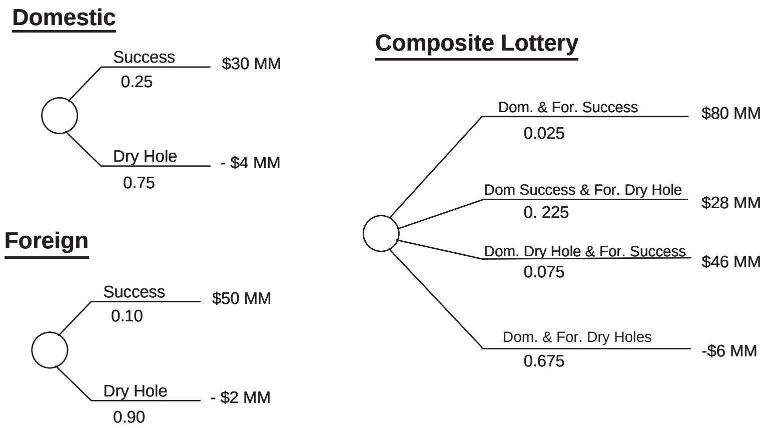


Fig. 2. Combining investments.

tain gamble as characterized by the properties of the domestic investment. 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. The certainty equivalent, then, for the composite lottery in Fig. 1b is equal to \$3.2 million. We can now compute the implied risk tolerance, R, for the composite lottery from the closed form expression in Eq. (1). In this example, the firm's risk tolerance value, R, \$40 million.

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 projects per year. To provide for reasonable computational tractability, we approximate the distribution of outcomes by treating each 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.

Approximating common utility functions from a mean–variance model provides a useful mathematical approach to estimating corporate utility functions. In the case of the normal distribution of investment returns, and an exponential utility function, Raiffa (1968) has shown that the certainty equivalent, C_x, is equal to the expected value (μ) minus the variance (σ^2) divided by two times the risk tolerance (R), that is:

$$C_x = \mu - \frac{\sigma^2}{2R} \tag{2}$$

Even in the case where returns are not normally distributed, Eq. (2) provides a good approximation for values of the firm's risk tolerance coefficient, R.

4. A model application – Exxon E&P

Similar to previous study of corporate risk tolerance, we infer the firm's risk attitude or policy by reconstructing the set of risky alternatives that were selected for capital allocations by the firm. We use publicly available data in this study, primarily from each company's 10-K filings as required by the SEC. These data do not provide detailed information on individual investment opportunities, but do provide a basis for reconstructing typical projects that were selected by the firm, and the number of projects that were selected. Furthermore, the data reported to the SEC is separated into domestic and international categories. Mean values from several years of experience have been used in some cases in order to reflect estimates of what decision maker's might have reasonably anticipated from the investment decisions rather than using the actual outcomes associated with a given year. This approach is consistent with our attempt to reconstruct the risk policy in effect at the time decisions were made about risky investments.

Two important parameter estimates are made when reconstructing from archival data the risks of the E&P projects selected by a firm. First, an estimate is made of the probability of a successful project that leads to the discovery of a commercial field. Second, an estimate is made of the reserves that will be discovered associated with a successful project. The archival data base 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, but by mean results over longer periods of time. For the estimate of the probability of success rate 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. Using similar reasoning, we use a rolling three-year average reserve addition per successful project over the 22 year study period as the best estimate of the reserves that would be associated with a successful project. The choice of the rolling average was used because a lag of several years 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 an example of our risk tolerance calculation we examine the case of Exxon–Mobil for the period 1981–2002. (Note that the risk tolerance measures for the entire 20 year study period include Exxon before and after the merger with Mobil Oil Corporation.) The data set and the calculated risk tolerance, R, pertain only to the firm's exploration and production (E&P) business unit. The statistical and archival data necessary to calculate the firm's risk tolerance are shown in Table 1 for the period 1997 though 2002.

Exploratory success rates are equal to the number of exploratory well successes divided by the number of exploratory wells drilled; as explained above. A three-year moving average calculation for probability of success for the foreign and domestic categories is utilized; that is p_{it} is equal to $(p_{it\text{-}1}+p_{it\text{-}2}+p_{it\text{-}3})/3$. Domestic and foreign reserve additions are based on the firm's reported new reserves added as a result of exploration activity; all reserves are based on *barrel of oil equivalence* (*BOE*). Net present value per BOE (I in Table 1) represents a measure of the value of the period's reserve additions through a calculation where all costs including leasehold/exploratory, drilling, completion, producing, lifting, administration and operational 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 represent an approximation of the outcomes for the total domestic and foreign exploration programs for each period.

Since we are interested in computing a distribution on individual investment (well) outcomes, we calculate an adjusted NPV per exploratory well as the 3-year rolling average sum of the adjusted NPV divided by the three-year rolling average sum of exploratory wells for each category over the 20-year period. The three-year rolling average approach is designed to approximate the ex ante modeling procedure, as discussed above. Since we are unable to know the specific characteristics of projects that were selected, this approach is designed to reconstruct, on a best efforts basis, the choices faced by the firm in terms of the nature of their capital projects and decisions they made under uncertainty.

The domestic and foreign mean NPVs for Exxon–Mobil are calculated as the number of successes (np) times the NPV/well. The variance ($np(1-p)$) of the distribution is calculated similarly. The grand mean and total variance represent the sum of the means and variances for the domestic and foreign investment distributions, respectively. The total certainty equiva-

Table 1
Risk tolerance calculation

Exxon	2002	2001	2000	1999	1998	1997
Change in SMCF due to reserve add.	$8,095,663	$6,468,205	$5,109,044	$4,063,523	$4,175,876	$6,042,948
$/BOE due to reserve additions	$6.68	$6.33	$7.68	$4.70	$3.37	$5.20
Productive wells, domestic	12	4	2	16	23	22
Productive wells, total	46	51	62	40	82	80
Productive wells, foreign	34	47	60	24	59	58
BOE discovery & ext., domestic	94,833	150,333	42,500	110,833	69,500	160,333
BOE discovery & ext., total	1,212,833	1,021,833	665,500	865,500	1,239,500	1,163,000
BOE discovery & ext., foreign	1,118,000	871,500	623,000	754,667	1,170,000	1,002,667
Domestic expl. budget	$276,000	$352,000	$219,000	$263,000	$409,000	$342,000
Total expl. budget	$1,163,000	$1,560,000	$1,288,000	$1,378,000	$1,974,000	$1,780,000
Foreign expl. budget	$887,000	$1,208,000	$1,069,000	$1,115,000	$1,565,000	$1,438,000
Success rate, domestic	57%	53%	54%	62%	62%	61%
Success rate, foreign	64%	61%	61%	58%	57%	55%
Domestic wells, n_1	17.0	8.0	4.0	27.0	43.0	30.0
Total wells	69.0	92.0	88.0	71.0	144.0	126.0
Foreign wells, n_2	52.0	84.0	84.0	44.0	101.0	96.0
Success payoff (X_1), domestic	$1,389,225	$2,144,564	$820,433	$1,101,927	$788,378	$1,717,745
Success payoff, (X_1) 3-yr. avg.	$1,451,407	$1,355,641	$903,579	$1,202,683	$1,358,152	$1,795,377
Success payoff, (X_2), foreign	$12,501,085	$10,304,970	$8,850,509	$7,245,817	$8,525,239	$10,966,899
Success payoff, (X_2) 3-yr. avg.	$10,552,188	$8,800,432	$8,207,189	$8,912,652	$8,057,125	$6,823,488
Expected payoff, domestic	$789,952	$1,138,472	$445,078	$683,492	$486,574	$1,040,190
Expected payoff, foreign	$8,032,596	$6,249,154	$5,439,814	$4,187,550	$4,828,023	$5,996,074

Per well payoff, domestic (X_1/n_1)	$160,242	$146,631	$100,675	$45,325	$78,180	$113,774
Per wellpayoff, foreign (X_2/n_2)	$135,133	$135,011	$126,679	$117,804	$77,581	$66,555
Mean well success, domestic	9.7	4.2	2.2	16.7	26.5	18.2
Mean payoff, domestic	$1,549,009	$622,730	$218,460	$759,069	$2,074,814	$2,066,893
Mean well success, foreign	33.4	50.9	51.6	25.4	57.2	52.5
Mean payoff, foreign	$4,515,151	$6,877,361	$6,540,355	$2,995,609	$4,437,504	$3,493,274
Variance-well success, domestic	4.2	2.0	1.0	6.4	10.2	7.2
Variance of payoff, domestic	$107,073,857,088	$42,837,591,659	$10,062,155,375	$13,064,503,571	$62,096,403,411	$92,756,954,455
Variance-well success, foreign	11.9	20.0	19.9	10.7	24.8	23.8
Variance of payoff, foreign	$218,095,163,775	$365,444,417,930	$319,287,700,685	$148,947,389,949	$149,300,638,104	$105,379,367,015
Total mean number of success:	43.1	55.2	53.8	42.2	83.7	70.7
Total mean payoff	$6,064,160	$7,500,091	$6,540,355	$3,754,678	$6,512,318	$5,560,167
Total certainty equivalent	$1,163,000	$1,560,000	$1,069,000	$1,378,000	$1,974,000	$1,780,000
Total variance (success)	16.1	22.0	20.9	17.1	35.0	31.0
Total variance in payoffs	$325,169,020,864	$408,282,009,589	$319,287,700,685	$162,011,893,520	$211,397,041,516	$198,136,321,470
Risk aversion level, *c*	0.030	0.029	0.034	0.029	0.043	0.038
Risk tolerance (RT)	$33.2	$34.4	$29.2	$34.1	$23.3	$26.2
CEQ/EV:	0.19	0.21	0.16	0.37	0.30	0.32
Domestic risk aversion, *c*	0.024	0.013	NA	0.076	0.054	0.037
Foreign risk aversion, *c*	0.033	0.031	0.034	0.025	0. 038	0.039
Domestic risk tolerance, RT	$42.1	$79.1	NA	$13.2	$18.6	$26.9
Foreign risktolerance, RT	$30.1	$32.2	$29.2	$39.6	$26.0	$25.6

Table 2
Risk tolerance results

Risk tolerance level (RT): 1983–2002 (millions of dollars) ordered on basis of E&P assets

Domain: worldwide

Company	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986	1985	1984	1983	E&P assets 2002
Exxon	33.2	34.4	29.2	34.1	23.3	26.2	38.0	33.3	21.2	39.4	31.1	21.7	19.6	17.7	24.5	20.0	21.0	17.5	20.8	28.8	152,664
Chevron	26.3	26.2	26.4	18.8	12.8	11.2	5.8	4.9	7.9	11.0	13.4	15.1	NA	NA	23.0	9.8	7.8	8.6	12.1	21.0	77,359
Phillips	NA	11.4	46.3	150.3	28.7	43.1	42.3	35.5	20.2	26.1	30.4	38.2	34.0	53.7	117.2	193.9	22.1	20.6	25.0	25.6	35,217
Conoco	NA	41.6	NA	57.4	45.7	37.4	17.5	26.7	40.8	41.6	38.4	46.6	55.7	48.7	51.7	51.3	NA	58.8	NA	NA	27,904
Anadarko	12.0	44.8	64.5	22.1	20.4	20.0	25.0	NA	14.6	11.4	18.4	16.3	23.1	6.1	9.4	8.9	11.5	6.9	11.7	NA	18,248
USX	NA	109.6	10.5	14.4	20.9	13.0	10.7	10.9	7.4	6.2	161.0	5.3	8.2	6.1	11.7	10.1	9.9	4.7	7.7	NA	17,812
Occident	20.6	45.7	79.0	NA	40.6	49.9	22.2	20.3	33.5	28.5	138.4	30.8	34.7	29.2	29.0	33.0	26.2	29.3	24.9	62.0	16,548
Burlres	54.4	54.2	0.9	6.8	12.3	7.3	4.1	4.5	5.8	6.4	4.2	3.9	3.6	5.8	3.5	3.0	3.1	7.8	NA	NA	12,716
Unocal	5.1	4.9	9.0	18.4	25.7	26.8	37.2	88.5	217.9	30.4	35.1	51.5	38.6	31.1	NA	NA	NA	NA	NA	NA	10,760
Apache	18.6	26.4	14.9	13.1	7.2	9.6	8.7	10.7	8.7	7.7	5.9	6.6	NA	NA	NA	NA	NA	NA	NA	NA	9,460
Dominion	25.3	31.5	71.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7,800
Murphy	NA	16.3	16.6	5.2	6.6	5.0	5.7	6.0	7.6	4.4	8.5	5.1	5.4	4.2	3.45	2.2	2.1	3.1	3.3	3.3	3,886
EOG	8.7	8.2	9.2	10.8	12.4	18.8	7.0	2.6	1.2	1.1	1.0	2.1	1.2	1.2	2.4	1.8	2.1	4.5	4.1	NA	3,814
Pioneer	1.9	3.8	1.7	3.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3,455
Noble	20.0	24.9	6.7	8.1	14.8	7.5	7.2	6.7	7.8	6.5	5.9	6.1	7.2	8.1	8.6	9.6	8.4	7.8	4.6	4.2	2,730
Pogo	2.9	1.9	1.4	1.2	2.1	1.3	0.8	2.6	3.5	5.5	NA	NA	NA	NA	NA	NA	5.6	7.6	8.0	9.0	2,492
Belco	8.1	10.4	3.4	1.3	1.7	2.1	2.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2,234
El Paso	15.9	11.4	19.2	21.3	29.6	27.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1,251
Cabot	13.7	10.3	6.2	4.6	3.5	9.0	NA	NA	NA	NA	NA	NA	NA	3.8	6.3	NA	6.5	3.8	3.5	2.8	1,055
Texaco	NA	NA	28.9	26.2	33.9	29.1	36.2	163.0	41.0	29.5	29.7	20.9	20.0	98.0	13.8	13.6	12.0	10.7	22.8	11.0	NA
Amoco	NA	NA	NA	NA	NA	NA	NA	5.6	11.8	15.1	11.6	7.9	4.5	11.1	14.9	12.9	8.0	11.4	14.3	13.3	NA
Arco	NA	NA	NA	NA	NA	NA	NA	23.1	98.2	55.1	33.0	28.3	33.6	22.8	26.4	28.5	32.9	25.9	23.9	34.3	NA
Union Pac	NA	NA	NA	18.5	16.7	26.7	22.7	24.3	17.1	18.0	13.9	13.2	14.2	17.3	30.3	34.4	17.0	18.8	27.1	29.0	NA

lent (C_x) for the overall set of projects in a given year is equal to the sum of Exxon's leasehold/exploratory budget allocations for domestic and foreign investments. Having defined all values in Eq. (2), except R, we now rearrange the equation and solve for the *implied risk tolerance coefficient* for each of the twenty year study periods (highlighted area on Table 1). Exxon's exploration and production business unit's implied *risk tolerance* (R) for each of the study periods is indicated on Table 1.

This same methodology was applied to the 50 largest (by E&P assets) U.S.-based oil companies from the period 1983–2002. Table 2 shows the implied risk tolerance levels for the top 23 firms in this sample for each year in the study period. The companies are shown in descending order of size, based on their reported E&P Assets for the year 2002. In the case of "NA" results for risk tolerance, insufficient data was reported for that year in order to make a statistically significant computation.

5. Differences in risk taking by region

In this expanded study of E&P risk-taking we discriminate between domestic and international E&P activities. As a result, we are able to explore the differences in risk taking by regions. We investigate differences that may exist in risk tolerance based on domestic versus foreign activities. Table 3 shows the results of this investigation.

On the basis of this analysis, there appear to exist systematic and statistically significant differences in observed risk tolerances between domestic and foreign activities. Note that the mean risk tolerance for domestic activities for all firms and all years is \$15.4 million while the mean risk tolerance for foreign activities is \$26.0 million. This difference is statistically significant at the 0.001 confidence level. We observe even larger differences in the case of certain firms. For example, over the entire study period the Chevron Corporation (and Chevron/Texaco) exhibits an average E&P risk tolerance for domestic activities of \$5 million. For foreign activities, it exhibits an average risk tolerance of \$29 million. It is important to note here that this observed risk tolerance is somewhat of an artifact of the study approach. Consider that the characteristics of foreign activities generally include larger capital outlays and higher risks than domestic activities. In fact, one might argue that the opportunity set for foreign activities is broader and more variable. If so, then just by the nature of a firm's higher emphasis on these opportunities a higher implied risk tolerance for foreign activities can be expected.

Table 3
Differences in risk taking

	Domestic	Foreign
Maximum	135.7	190.0
Minimum	0.4	4.1
Mean	15.4	26.0
Variance	290.7	1005.0
Standard deviation	17.0	31.7
Size (n)	447	252
Confidence interval	16.7	29.3
	14.5	22.7

6. Corporate risk tolerance vs. firm size

Intuitively one might argue that the degree of risk aversion decreases as wealth increases or, alternatively, the degree of risk tolerance increases with wealth. As we accumulate more and more wealth our willingness to take financial risk, on an absolute basis, increases. Similarly, as the firm grows and accumulates wealth its ability to take on larger, more risky projects also grows. In support of this argument, Howard (1988) shows in a cursory study of a number of large companies 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.

For oil companies, an appropriate measure of firm size is the Standardized Measure of Discounted Future Net Cash Flows (SMCF). This figure represents a reasonably consistent 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.

Paragraphs 30–34 of Statement 69 of the United States Security and Exchange Commission Staff Accounting Bulletin require the disclosure of the standardized measure of discounted future net cash flows from production of proved oil and gas reserves, computed by applying year-end prices of oil and gas (with consideration of price changes only to the extent provided by contractual arrangements) to estimated future production as of the latest balance sheet date, less estimated future expenditures (based on current costs) of developing and producing the proved reserves, and assuming continuation of existing economic conditions.

Statistical analysis shows that there exists a significant positive relationship between firm size (SMCF) and corporate risk tolerance (RT). Fig. 3 shows a plot of the log(SMCF) versus the log(RT) with the observed values and the fitted regression line. There exists a strong positive relationship between corporate risk tolerance and the size of the firm. This confirms the rather intuitive notion that, on an absolute risk taking basis, the larger the firm the more willing it is to take on risky projects.

Since we know that larger firms, on average, will have a higher risk tolerance than smaller firms, it may be more important to evaluate relative risk tolerance rather than absolute risk tolerance. In order to accomplish this we need to utilize a measure of risk propensity that controls for firm size. For example, consider a simple drilling opportunity where the chance of success is 40% and the success payoff is $50 million while the failure payoff

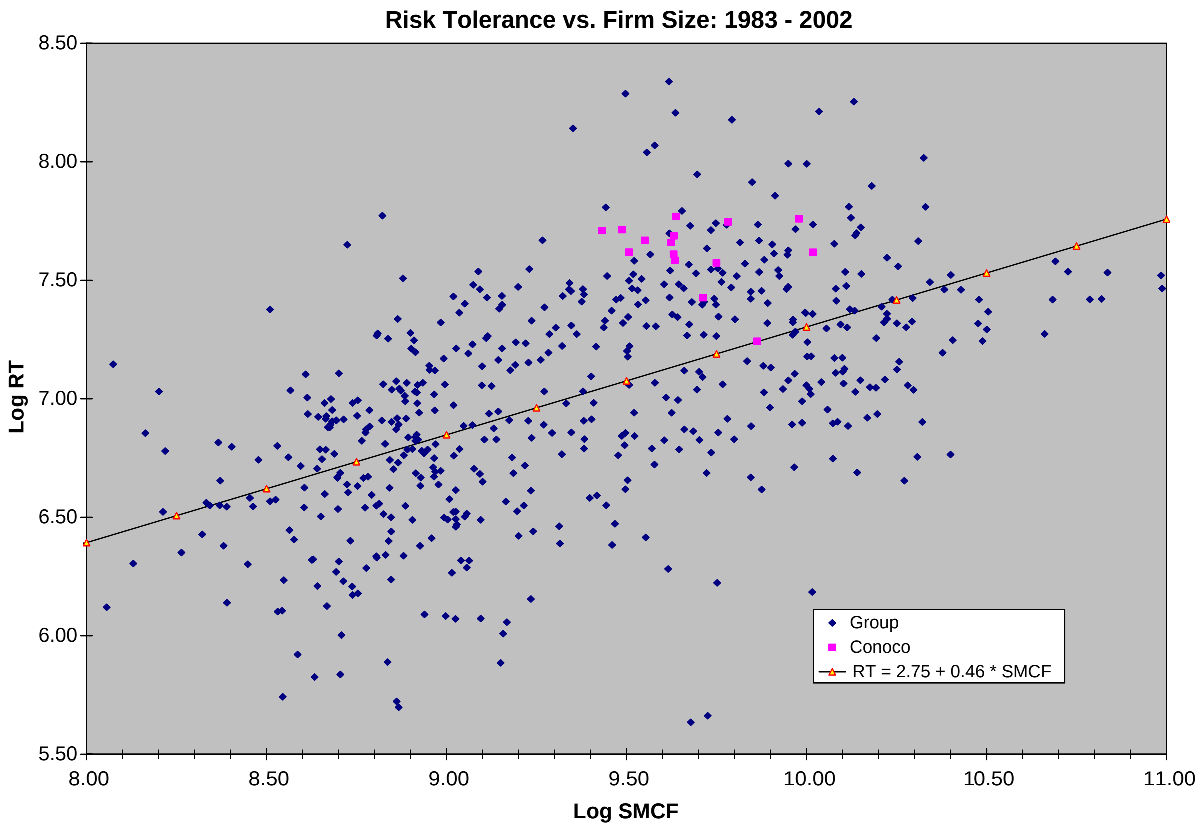


Fig. 3. Risk tolerance and firm size.

Table 4
Risk tolerance ratio

Risk Tolerance Ratio (RTR) Example			
	Firm 1	Firm 2	Firm 3
$SMCF_i$ (wealth)	\$1000 MM	\$100 MM	\$10 MM
RT_i' (predicted)	\$100 MM	Firm 2	Firm 3
RT_i (actual)	\$50 MM	\$20 MM	\$2 MM
RTR_i (RT_i/RT_i')	0.50	1.33	1.0

is \$10 million. Now assume we have two firms, one with a \$500 million capital budget and one with a \$50 million capital budget and that both these firms agree to accept this project. On an absolute risk tolerance basis we might say that these firms are equivalent but on a relative risk-taking basis the smaller firm is much more aggressive in its risk-taking. We investigate this important difference by utilizing the *risk tolerance ratio* (*RTR*) measure.

The RTR measure is constructed to control for firm size. For any firm i, 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 of firm i as a function of size (SMCF) for that same period, as defined by the regression line in Fig. 3. An example of the risk tolerance calculation is shown in Table 4. The RTR measure describes the firm's relative risk propensity as compared to other 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. An RTR value less than 1.0 implies a weaker propensity to take risk than firms of equivalent size. Table 5 presents the values for each of the top 23 firms in our study. As an example, compare the relative risk propensities of Chevron (RTR = 0.66) and Conoco (RTR = 3.37) for the year 2000. The RTR measure implies that Chevron's E&P unit, given its total SMCF value, was less willing to take risk than firms of its equivalent size; conversely,

Table 5
Risk tolerance ratio results

Risk tolerance ratio: 1983–2002 (millions of dollars) ordered on basis of E&P assets

Domain: worldwide

Company	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	1988	1987	1986
Exxon	0.52	0.71	0.68	0.64	0.92	1.09	0.77	1.55	1.08	0.86	0.58	0.57	0.98	0.75	0.83	0.52	0.63
Chevron	0.56	0.47	0.66	0.46	0.19	0.21	0.40	0.59	0.60	0.74	NA	NA	1.15	0.49	0.40	0.35	0.48
Phillips	1.66	9.29	2.34	2.87	2.22	2.28	1.56	2.07	2.29	3.14	2.16	3.75	9.08	16.35	1.85	1.44	1.62
Occident	3.25	NA	3.19	3.70	1.43	1.61	2.76	2.81	13.59	3.06	2.57	2.41	2.77	2.93	2.27	2.08	1.68
El Paso	0.99	1.91	3.41	3.28	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Conoco	NA	2.92	3.37	2.42	1.00	1.80	2.99	3.47	2.80	3.71	3.48	3.57	4.41	4.63	NA	4.28	NA
Anadarko	2.27	1.60	2.01	2.06	2.03	NA	1.78	1.46	2.32	2.25	3.16	0.84	1.31	1.31	1.64	1.09	1.77
Burlres	0.03	0.41	0.83	0.50	0.23	0.38	0.50	0.54	0.35	0.36	0.32	0.59	0.40	0.41	0.44	0.83	NA
Texaco	0.96	1.01	2.32	1.33	1.38	7.82	2.24	1.83	1.56	1.16	0.88	4.87	0.78	0.75	0.63	0.46	0.90
Unocal	0.42	1.19	2.46	1.98	2.21	6.05	16.18	2.20	2.31	3.38	2.17	1.98	NA	NA	NA	NA	NA
USX	0.51	085	1.77	0.88	0.60	0.75	0.53	0.48	11.74	0.41	0.52	0.44	0.90	0.76	0.71	0.27	0.45
Apache	0.68	0.93	0.75	0.89	0.72	1.15	1.09	1.04	0.89	1.03	NA	NA	NA	NA	NA	NA	NA
Dominion	3.92	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Murphy	1.52	0.59	1.21	0.72	0.66	0.92	1.36	0.82	1.56	1.05	0.88	0.70	0.62	0.38	0.37	0.43	0.44
EOG	0.51	1.02	1.16	1.82	0.59	0.30	0.15	0.14	0.12	0.28	0.16	0.17	0.37	0.26	0.28	0.57	0.57
Pioneer	0.11	0.26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Noble	0.50	0.96	2.12	0.93	0.71	0.86	1.27	1.10	1.15	1.26	1.29	1.59	1.83	1.94	1.73	1.55	0.90
Pogo	0.16	0.19	0.44	0.29	0.13	0.56	0.88	1.36	NA	NA	NA	NA	NA	NA	1.13	1.51	1.59
Cabot	059	0.84	0.62	1.59	NA	NA	NA	NA	NA	NA	NA	0.96	1.66	NA	1.80	0.88	0.75
Belco	0.39	0.27	0.39	0.44	0.51	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Amoco	NA	NA	NA	NA	NA	0.26	0.56	0.75	0.52	0.36	0.17	0.45	0.67	0.59	0.36	0.42	0.55
Arco	NA	NA	NA	NA	NA	1.16	5.15	3.57	1.77	1.66	1.43	1.11	1.55	1.62	2.01	1.18	1.05
Union Pac	NA	1.30	1.39	2.28	1.67	2.59	1.93	2.28	1.62	1.55	1.59	2.01	3.97	4.45	2.23	1.97	2.75

Conoco could be characterized as an aggressive risk taker compared to other firms in the industry that had similar SMCF values.

7. Competitor analysis and performance effects

Fig. 3 shows a plot of risk tolerance versus size for all companies and all years of the study. However, firms might be more interested in examining a particular peer group of firms and their willingness to take financial risks. This could have broad implications on a number of dimensions including competitive bidding issues as well as potential partnership decisions among firms. Fig. 4 shows a more focused competitive analysis that compares a select group of firms and how they stack up in terms of risk-taking during the study period. The bold line included in this graph is the industry regression line as noted earlier in this paper. We see, for example, that Chevron falls consistently below the regression line (low risk propensity) while Shell Oil lies consistently above the regression line (high risk propensity). Interestingly, we wee that Conoco and Phillips are generally high risk-takers while Chevron and Texaco consistently fall below the line. This may also have implications in terms of recent merger activities within the industry, as well as propositions about future merger and acquisition activities. The important implication here is that firms can get a sense of relative risk taking by firms in their peer group which may, in certain cases, influence competitive actions.

In addition to understanding the competition, managers are also concerned with establishing the appropriate level of risk taking for their firms. Managers in the E&P sector are confronted daily with important decisions characterized by a high degree of risk and uncertainty. Developing a coherent risk policy for the firm and acting on that policy can be an important consideration. Equally important is understanding the impact of a particular risk policy. So managers are confronted with two important issues: setting a risk policy and evaluating the effect of that policy on business unit performance. This study investigates that relationship, if any, between the degree of corporate risk taking and E&P performance.

In this study, E&P performance is measured in terms of return on exploration and production assets (ROA). For purposes of return calculation, income is defined as earnings before interest but after taxes. We utilize an accounting-based measure rather than a market-based measure (such as stock price) because we are investigating the E&P business unit of the

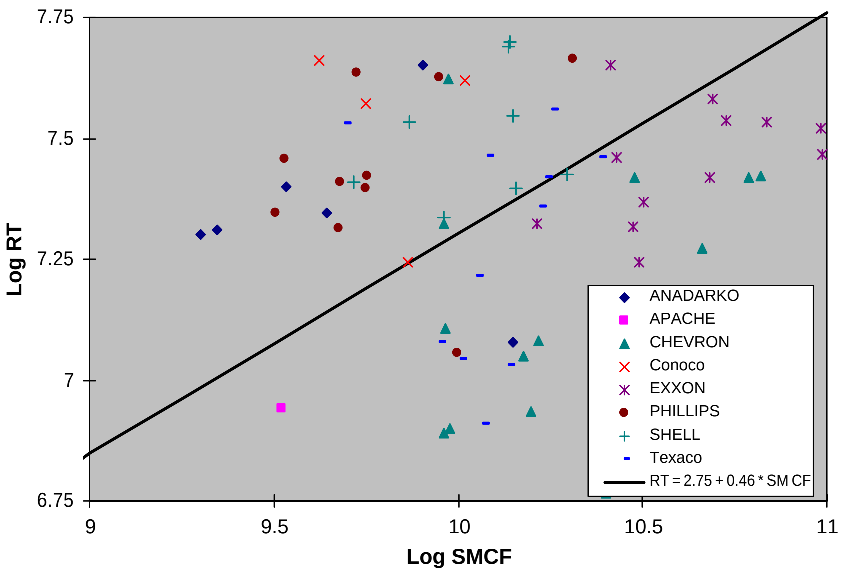


Fig. 4. Competitor analysis–risk tolerance.

firm. The risk-taking measure we utilize is the previously defined risk tolerance ratio (RTR) measure. We distinguish among firm risk propensities by using four categories of risk tolerance. Those categories are defined along the dimension of RTR and are shown in Table 6, which also summarizes the statistical information relating to return on assets for the set of firms within each of these risk tolerance categories.

An analysis-of-variance (ANOVA) statistical test indicates that there exist significant differences in E&P performance as it relates to risk taking categories. *With regard to achieving higher return on assets, the ANOVA test indicates there exists an optimal range of corporate risk tolerance. E&P firms categorized with High Risk Tolerance levels (RTR>2.50) demonstrate significantly higher returns (8.2%) than those firms that exhibit less tolerance for risk-taking*. Firms which are willing to implement risk policies characterized by RTR values greater than 2.5 are more likely to achieve superior returns. These results are statistically significant at the 0.05 confidence level. For those firms in the remaining risk tolerance categories (Low, Average, and Moderate) this would suggest that they have exercised highly risk averse behavior, and in so doing have reduced their opportunity for higher returns. The resulting effect is the selection of a sub-optimal risk tolerance level and less than superior asset returns. Note that firms do move from category to category over time so the results here are cross-sectional in nature. Rather than suggesting any one firm's policies are optimal these study results provide some evidence that a particular risk tolerance policy may be appropriate in terms of improving overall E&P performance.

8. Conclusions and implications

This study utilizes a measure of corporate risk taking that conforms more closely to the manner in which managers and decision makers conceptualize the notion of risk. In addition, the risk tolerance ratio is used to quantify and analyze the relative risk propensities of the top 50 U.S.-based E&P firms who vary significantly in size. The important implication is that we are able to make stronger inferences about causal relationships between risk taking and performance over time, thus understanding better the effects of risk policies implemented by E&P firms.

The study results indicate that those firms who behave in a highly risk averse manner generate less than superior asset returns. The firms in this study who reveal a relatively high risk propensity, compared to their competitors, generate significantly higher asset returns. This finding has profound implications with regard to how E&P managers should set risk policies for their firms. Those firms who can identify their appropriate risk tolerance level, and make allocation decisions based on that risk tolerance, will demonstrate significantly higher returns than those firms implementing lower and perhaps inappropriate risk tolerance levels.

Understanding corporate risk tolerance and its impact on E&P firms' investment decisions has

Table 6
Risk tolerance (RTR) vs. Performance (ROA)

RTR on RT: Total	Risk tolerance ratio (RTR)			
RTR Group:	High	Moderate	Average	Low
RTR:	RTR >2.5	2.5 ≧ RTR > 1.5	1.5 ≧ RTR > .5	.5 ≧ RTR
Maximum	0.500	0.281	0.320	0.316
Minimum	−0.137	−0.342	−0.370	−1.149
Mean	0.082	0.049	0.047	0.025
Variance	0.009	0.007	0.006	0.020
Standard deviation	0.095	0.085	0.078	0.140
Size (n)	84	119	200	107
Confidence interval	9.93 %	6.15 %	5.59 %	4.76 %
	6.51 %	3.59 %	3.78 %	0.31 %

implications with regard to competitor analysis on a number of dimensions. Decisions regarding competitive bidding, partnership selections, and even merger and acquisition candidates can be influenced by firms' risk propensities. Tracking and understanding competitors' risk taking actions can provide valuable insights that may influence a firm's competitive behavior. It is one of many important dimensions that E&P firms should consider in terms of their strategic decision making.

References

Clemen, Robert T., 2001. Making Hard Decisions. Duxbury/Thomson Learning, Pacific Grove, CA, pp. 543–550.

Cozzolino, J., 1977. A simplified utility framework for the analysis of financial risk. Economics and Evaluation Symposium of the Society of Petroleum Engineers. Dallas, Texas.

Holloway, C.A., 1979. Decision Making Under Uncertainty: Models and Choices. Prentice-Hall, Englewood cliffs, N.J.

Howard, Ronald A., 1988. Decision analysis: practice and promise. Manage. Sci. 34 (6), 679–695.

Luce, R.D., Raiffa, H., 1957. Games and Decisions. Wiley Publishing Co., New York.

Raiffa, H., 1968. Decision Analysis: Introductory Lectures on Choices Under Uncertainty. Addison-Wesley, Reading, Mass.

Spetzler, C.S., 1968. The development of a corporate risk policy for capital investment decisions. IEEE Transactions on Systems Science and Cybernetics Institute of Electrical and Electronics Engineers SSC-4.

Walls, M.R., Dyer, J.S., 1996. Risk propensity and firm performance: a study of the petroleum exploration industry. Manage. Sci. 42 (No. 7), 1004–1021.