Do Firms Underinvest in R&D? - The Case of R&D in Oil and Gas Recovery

*By Ernest M. Zampelli**

The application of new technologies has had a profound effect on oil and gas exploration and development over the past 15 years. Examples include horizontal drilling, 3-D seismic and advanced recovery techniques such as CO_2 injection.[1] These and other advances are believed to have contributed significantly to the improvements in finding rates, success rates, finding costs and lifting costs which have occurred over the past decade.

Technology is expected to play an even more important role in resource development in the future. Though the world is endowed with a considerable volume of undiscovered oil and gas resources, recovery of significant portions of this resource base is contingent on the rate of advancement in extractive technology and hence on the level of investment in R&D for oil and gas recovery by firms in the oil and gas industry.[2] This analysis attempts to identify the major determinants of R&D investment. The approach follows Schumpter (1950) who emphasized the importance of firm size and market structure as well as the more recent literature which stresses the role of a firm's financial structure, especially the impact of cash flow on investment behavior. Previous research on R&D expenditures by firms in the petroleum industry by Baltagi and Griffin (1989) considered the latter influence but surprisingly did not examine the influence of the former. Moreover, their analysis examined total R&D expenditures which are comprised of expenditures not only for oil and gas recovery, but for petroleum refining processes and applications, coal, other energy sources such as solar and geothermal, and nonenergy areas such as chemical production. Accordingly, their analysis has little to say specifically about the determinants of R&D expenditures on oil and gas recovery. The following analysis is an attempt to remedy this deficiency. An econometric model is developed in which a firm's R&D expenditures on oil and gas recovery per barrel of production are hypothesized to be a function of the firm's size, its level of proved reserves, the share of proved reserves accounted for by natural gas, cash flow relative to assets, the price of oil, the share of fixed capital invested in oil and gas production, unobserved firm specific effects and merger activity. Using Tobit estimation for censored data, the model is estimated for 18 firms over the period 1978 through 1993.

Determinants of R&D Expenditure Levels

The Schumpeterian hypothesis that larger firms will engage in more innovative activity requires that any model of R&D activity incorporate the potential impact of firm size. In this analysis firm size is measured by beginning of year total assets. Since the likely relationship is probably nonlinear, the model includes the natural logarithm of beginning of year total assets as the explanatory variable with an expected positive sign consistent with the Schumpeterian hypothesis.

It is also critical to remember that the private incentives to engage in R&D are profoundly affected by the problem of nonappropriability, i.e., the inability of the firm conducting the R&D to capture the total benefits of its investment. Spence (1984), for instance, found that a decrease in appropriability, i.e., an increase in spillovers to others from the R&D, reduces the incentives to invest in R&D. One implication for private sector R&D in oil and gas recovery is that firms with small levels of proved reserves may have little, if any, incentive to engage in R&D activity. Consequently, one would expect R&D spending per barrel of production to rise with increases in reserves.

R&D is an inherently risky form of investment with long lead times. Together with the problems of nonappropriability and possible capital market imperfections, this will likely lead firms to rely on internal capital markets for R&D financing. Hence one would expect to find that a firm's financial characteristics are important in determining the level of its R&D spending. Following some of the most recent literature on determinants of investment spending, the model includes cash flow from operations (per dollar of assets) as an explanatory variable. It is calculated basically as net income plus depletion, depreciation and amortization expenses plus deferred taxes. Cash flow is expected to positively affect the level of R&D investment.

The benefits of R&D that improves oil and gas recovery are a function of the expected market value of the incremental production. Conservatively assuming constant real prices in the future, this analysis proxies expected market value by the current real world oil price.

As suggested above, a firm's R&D spending per barrel of oil equivalent (BOE) reserves is apt to be a function of its total BOE reserves. This, however, ignores the differences between oil and gas in terms of the opportunities for and payoffs from R&D expenditures. For example, horizontal drilling, one of the more important advances of the last decade has almost been exclusively applied to oil. Chemical, miscible and thermal recovery techniques are generally recognized as the most promising methods for the enhanced recovery of oil. There are exceptions. Advanced fracturing techniques lie largely in the domain of natural gas. Three dimensional seismic technology is applicable to both oil and gas but is mainly used in offshore exploration and development. In other words, a firm's level of R&D spending is a function not only of its total reserves, but also the oil/gas composition and the geographical location of those reserves and hence proved reserve share variables are included to control for these influences.

To control for the varying degree of diversification of the firms in the sample in their oil and gas recovery intensities, the model also includes the share of the firm's total fixed capital stock (at the beginning of the year) which is invested in oil and gas production. A firm's level of investment in R&D is also a function of its specific corporate culture and other unobserved firm specific effects. These are controlled for by a set of 11 firm dummy variables for those companies that generally invest in R&D for oil and gas recovery. An overall constant term is included which represents the set of those seven firms in the sample that report virtually zero spending on R&D over the sample period.

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[1] See footnotes at end of text.

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It is important to note that the model also attempts to incorporate the influence of the major mergers in the oil and gas industry during this time period. The mergers accounted for are: Chevron/Gulf, Texaco/Getty, Mobil/Superior and Occidental/Cities Service. For consistency, these firms were treated as single entities throughout the sample period, i.e., for those years prior to a merger the data for the firms involved were combined to form a single entity. Four of the firm specific dummy variables, therefore, are associated with these combined entities. To examine whether the behavior of these combined entities is altered after the formal merger takes place, the model includes merger dummy variables which are equal to 1 beginning in the year immediately after the merger takes place and 0, otherwise.

Finally the model includes a dummy variable to capture the potential impact from the federal R&D tax credit which existed for the 1981-86 period.

Algebraically, the model can be written as:

$$R\&D = \alpha_0 + \alpha_1 LNSIZE + \alpha_2 CF + \alpha_3 LNRES + \alpha_4 GASSHR + \alpha_5 OGKSHR + \alpha_6 LNPOIL + \alpha_7 CREDIT + \alpha_8 EUROPE + \alpha_9 CANADA + \alpha_{10} MEA + \alpha_{11} OFFSHR + \alpha_{12} OTHSHR + b_i FD_i + b_j MERGE_j + e$$

Where:

R&D = research and development expenditures per barrel of production (in BOE);
LNSIZE = natural logarithm of beginning of year total assets;
CF = cash flow from operations per dollar of total assets;
LNRES = natural logarithm of reserves (in BOE);
GASSHR = share of reserves accounted for by natural gas;
OGKSHR = share of total fixed assets invested in oil and gas production at the beginning of the period;
LNPOIL = natural logarithm of the world oil price in 1994 dollars;
CREDIT = 1 if year between 1981 and 1986, 0 otherwise;
EUROPE = share of reserves located in Europe;
CANADA = share of reserves located in Canada;
MEA = share of reserves located in the Middle East and Africa;
OFFSHR = share of reserves located in the U.S. offshore;
OTHSHR = share of reserves located in other areas, except for U.S. onshore;
FD_i = firm specific dummy variable, i = 1 to 11;
$MERGE_j$ = merger dummy variables, j = 1 to 4;
e = random error term.

The model is estimated using data from the United States Energy Information Administration Financial Reporting System over the time period 1978-93. Included in the sample are Amerada Hess, AMOCO, Ashland, ARCO, Burlington Resources, Coastal, Chevron, Conoco, Exxon, Fina, Kerr-McGee, Mobil, Occidental Petroleum, Phillips, Texaco, Unocal, Union Pacific and USX (Marathon).

Estimation and Results

A substantial fraction of the firms in the sample reported several or more years of zero expenditures on R&D for oil and gas recovery. The application of ordinary least squares under these circumstances will yield biased and inconsistent estimates (Green, 1990). Consistent estimates can be obtained through the use of the Tobit estimation technique. An additional econometric problem is one of cross-sectional heteroscedasticity. The equation is estimated using Tobit with a correction for multiplicative heteroscedasticity where the firm specific error variance is a function of the firm specific dummy variables.

The results are reported in Table 1. Consistent with recent evidence, the coefficient on CF is positive. However, it is statistically insignificant. Apparently, a firm's financial structure in terms of cash flow and interest obligations is a relatively unimportant factor in determining a firm's level of R&D spending on oil and gas recovery. The negative coefficient on GASSHR is consistent with the view that R&D expenditures for oil and gas recovery are motivated by oil recovery as opposed to both oil and gas recovery. The coefficient is, however, statistically insignificant.

Table 1
Determinants of R&D Expenditures on Oil and Gas Recovery Per Barrel of Oil Equivalent Production

Variable	Estimate	(t-value)
Constant	-1.92	(3.11)[1]
LNSIZE	0.05	(3.41)[1]
CF	0.002	(0.07)
LNRES	0.06	(2.29)[2]
GASSHR	-0.18	(1.39)
OGKSHR	-0.02	(0.61)
LNPOIL	0.035	(2.75)[1]
CREDIT	0.016	(2.22)[2]
EUROPE	0.26	(2.21)[2]
CANADA	-0.22	(1.93)[3]
MEA	0.033	(0.28)
OFFSHR	0.23	(1.65)[3]
OTHSHR	0.1	(1.26)
MERGE1	0.017	(1.22)
MERGE2	-0.013	(0.75)
MERGE3	-0.07	(2.05)[2]
MERGE4	0.095	(3.14)[1]
Number of Observations	228	
Log-Likelihood Statistic	369.6	

[1] Significant at one percent
[2] Significant at five percent
[3] Significant at ten percent

The results are also consistent with the view that R&D expenditures per barrel rise with increases in reserves because the returns to R&D are plagued by nonappropriability. Specifically, the positive and statistically significant coefficient on LNRES indicates that firms with larger reserves tend to be more R&D intensive than their smaller counterparts.

The results do not indicate a significant relationship between R&D spending and the share of total fixed assets devoted to oil and gas production. The estimated coefficient on OGKSHR is statistically insignificant.

The presence of the R&D tax credit over the period 1981-1986 appears to have had a positive and statistically significant impact on R&D intensity. Additionally, the results show that the expected market value of production as proxied by LNPOIL has a positive and significant impact on R&D spending levels.

Generally, the coefficients on the firm dummy variables are statistically significant indicating that differences in unobserved firm specific characteristics are important in explaining the variation in R&D spending across the firms.

The results indicate that the location of a firm's reserves plays a major role in the firm's level of R&D spending. Specifically, the positive and significant coefficient on EUROPE indicates that firms with a large share of their reserves in Europe will have higher expenditure levels on R&D. Given the harsh operating environment of the North Sea (the principal location of activities in Europe), this result is not surprising. The positive and significant coefficient on OFFSHR is expected given that the U.S. offshore represents an area in which technological advances are a source of significant competitive advantage. The coefficient on CANADA is both negative and significant. This is not entirely unexpected given that Canada has the dubious distinction of having the highest finding costs and the lowest finding rates for the firms in this sample.[3] The estimated coefficients for the remaining geographical share variables are highly insignificant.

The results indicate that the impacts of the different mergers in the industry over the sample period were mixed. Two of the mergers had no statistically significant impact on R&D intensity. One had a negative and significant impact on investment in R&D which is a result consistent with Jensen's free cash flow hypothesis and with the more simple view that the reduction in R&D spending reflected the elimination of duplicative R&D efforts. It may also suggest economies of scale in R&D activity. The other had a positive and significant impact on R&D activity indicating a possible reduction in the problem of nonappropriability as a result of the merger.

Summary and Conclusions

Using a panel data set of 18 large petroleum companies over the 1978-93 time period, this study has examined the determinants of R&D expenditures for oil and gas recovery. The basic model hypothesized that R&D expenditures per barrel of production for each firm are a function of the firm's size, its level of reserves, the share of reserves accounted for by natural gas, cash flow relative to assets, the price of oil, the share of assets in oil and gas production, the geographical location of its reserves, the R&D tax credit, unobserved firm specific effects, and merger activity. The model was estimated using the Tobit estimation procedure for censored data with correction for heteroscedasticity.

The results are consistent with the view that as a result of the problem of nonappropriability, only firms with very large reserves have adequate incentives to engage in R&D. The analysis also indicates that incentives to engage in R&D are far from uniform. Specifically, firms that have a large share of their reserves in Europe and the offshore U.S. will tend to invest more in R&D, *ceteris paribus*. Likewise, firms with a large share of their reserves in Canada appear to invest less in R&D.

The impacts of merger activity were shown to be mixed. In two cases, the results indicted no statistically significant effects of mergers on R&D intensity. In one of the other two cases, the results show a negative association between the merger and R&D effort while in another they show a positive effect on R&D expenditures for oil and gas recovery.

Footnotes

[1] See Moss (1994) for a discussion of technological innovations in exploration and development.

[2] See Fisher (1994), Natural Petroleum Council (1992) and EIA (1990).

[3] According to Ellsworth and Forbes (1994) finding costs (finding rates) for the FRS companies are highest (lowest) in Canada. See also Energy Information Administration, *Performance Profiles of Major Energy Producers*, 1993, p 35.

References

References are available from the author on request.

China... *(continued from page 29)*

the South China Sea could well become a "Chinese lake" by the end of the century.

Footnotes

[1] BP *Statistical Review of World Energy*, London, June 1995, pp.5-8.

[2] Gerald Segal, "Tying China into the International System," *Survival*, vol.37, no. 2., Summer 1995, pp.62-63.

[3] BP *Statistical Review of World Energy*, p.2.

[4] Mark J. Valencia, "China and the South China Sea Disputes," Adelphi Paper. 298 (Oxford: Oxford University Press for the IISS, 1995), p.10.

[5] *Wall Street Journal*, 10 October 1994, p.7.

[6] *Beijing Review*, 1-7 May 1995, p.7.; also Nicholas R. Lardy, "China in the World Economy" (Washington DC: Institute for International Economics, 1994), pp. 14-25.

[7] *Financial Times* report on China, 2 June 1995, based on a study, "Asia-Pacific Profiles" the Australian National University, Canberra.

[8] Paul Dibb, "Towards a New Balance of Power in Asia," Adelphi Paper 295 (Oxford: Oxford University Press for the IISS, 1995), p-27.

[9] Michael Leifer, "Chinese Economic Reform and Security Policy: The South China Sea Connection," *Survival*, vol.37, no. 2., Summer 1995, p.44.

[10] *Wall Street Journal*, 10 October, 1994, p. 7.

[11] *Newsweek*, 20 March 1995, p-33.

[12] Valancia, "China and the South China Sea Disputes," pp. 54-57.
