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U.S. oil and natural gas reserve prices, 1982–2003

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Abstract

A time series is estimated of in-ground prices of U.S. oil and natural gas reserve prices for the period 1982–2003, using market transaction data. Reserves sold are considered as proved; errors in this respect may affect estimates, in either direction. The data are also used to examine the impact of reserve status, production rate, and well head prices, on reserve prices. Both oil and gas current values rose after 2000. In real terms, the reserve value of oil rose sharply in 2003, but stayed below the 1985 peak; that of gas remained below the mid-1980s. Oil reserve values hold for the worldwide industry; gas values only for North America.

JEL classification: L71, Mining, extraction and refining: hydrocarbon fuels; Q30, Non-renewable resources and conservation, general

Keywords: Oil and gas; Producing properties; Reserve sales; In-ground values; Time series

1. Introduction

The main object of this research is to estimate a time series for the unit value of in-ground proved oil reserves and natural gas reserves in the United States. There are good official statistics of the physical quantities. Total in-ground value equals quantity times unit value, which is our objective.

Such a series has several uses. First, it provides information about the national income and wealth, which includes mineral reserves. About 70% of mineral value-added in 1997

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was oil and natural gas. [Census Bureau: Manufacturing and Mining] Some such proportion governs mineral wealth in the ground. The U.S. Government itself owns land that includes large reserves. The Bureau of Economic Analysis (BEA) has deplored the lack of reserve price data. They are estimated here.[1]

Second, there is much interest, when calculating national income and product, to make full allowance for current consumption of minerals. If the oil and gas reserve values are known, capital consumption of minerals is the difference in reserve value from the beginning to the end of the period. This difference can then be partitioned into the change in physical amount held and the change in the asset value.

Third, the condition of the oil and gas industries in the United States continues to attract attention. The value of an in-ground unit compared with its reproduction cost is a crucial fact. Unfortunately, we can no longer make this comparison. Since 1991, there has been no compilation of capital expenditures for finding and developing hydrocarbons, formerly published (see Adelman, 1992, pp. 19–20). Information from the Department of Energy is not a substitute, since it is based on a partial and unrepresentative sample, omitting much of relevance.

Fourth, reserve values have important implications for the basic theory of mineral resources.

Our paper is organized in three sections. Section 2 reviews the basic data used to estimate reserve prices. The results of reserve price estimation–mainly from regression analysis–are presented and discussed in Section 3. Concluding remarks are made in Section 4.

2. Review of transaction data

We want to assemble information on the amounts paid for in-ground reserves of oil and natural gas to enable us to estimate reserve prices. For a period of 20 or more years, the Scotia Group has been collecting data on reserve related transactions in the U.S. and has sought to identify the value of purchases and sales of reserve assets.[2] In what follows below, first we comment on the nature of the Scotia Group transaction data we employ. Second, we examine the Scotia data series, assembled on an annual basis.

2.1. The Scotia Group Database[3]

The information in the database is collected entirely from sources in the public domain. The version of the database used has nearly 6000 transactions of which about 60% have transaction price data and around 30% have both price and reserve information. These are the transactions on which we focus.

[1] The paper draws on information in Adelman & Watkins (in press—MIT-CEEPR Working Paper, forthcoming—which is in part an update of Adelman & Watkins, MIT-CEEPR Working Paper 96-004WP).

[2] The Scotia Group was founded in 1981 and specializes in the technical and economic analysis of projects, properties and companies.

[3] See Scotia Group Documentation “Description and Discussion of the Database” Mimeo, Jan. 1995.

Some transactions involve non-reserve assets such as pipelines, plants and equipment, goodwill, strategic elements and the like. "Strategic" acquisitions, especially, may involve significant goodwill. Where values of tangible ancillary assets are known, they have been subtracted from the purchase price; where the purchaser assumes debt, its value is added. The resulting transaction values are referred to in the Scotia database as 'adjusted prices'.

Reserves are reported in millions of barrels of oil (mmbbls) and billions of cubic feet of gas (bcf). Producing rates, where available, are reported in thousands of barrels per day of oil (mb/day) and millions of cubic feet of gas per day (mmcf/day). Reserves are treated as proven, developed and on production—unless there is additional information. Buyers and sellers may differ in their reserve assessments, even for proved reserves. However, no such discrepancies were disclosed in the transactions employed. There is no information on expected reserve appreciation that may underlie a given transaction.

International and Canadian transactions are excluded. So are transactions reported in terms of equivalent volumes of oil and gas, but with conversion factors unknown, such that volumes of oil and gas cannot be derived. Data for these transactions are therefore incomplete, and we exclude them. The database generally excludes company stock transactions because reserves cannot be identified.

Our working assumption–that the reserves changing hands are proved, developed, and producing–is not always true. A transaction could involve non-producing reserves. If so, it may well include reserves normally classified as proved undeveloped or prospective reserves (i.e., probable or possible) even though we have attempted to exclude transactions involving undeveloped reserves from our database.

Suppose parties have included in "reserves" some undeveloped oil or gas deposits. (Some buyers will try to impress the financial community by reporting undeveloped reserves as developed; others, seen as overpaying for developed reserves, will not be well regarded—we cannot say which event is more probable.) Then the observation we calculate, dollars per mcf or barrel-in-ground, could be too low as an estimate of the market value of a barrel of developed reserves. Suppose now the contrary, that the sellers have lumped undeveloped reserves with any undeveloped acreage and other producing assets. Then the total value is too high, because it includes more than the value of developed reserves. We cannot identify either type of error, understatement or overstatement, and hence must consider both of them as contributing to chance variations, along with other sources of error. This would increase the error of estimate.

2.2. Description of transaction data[4]

Annual data on the observations selected are shown in Table 1, columns 2, 3 and 4. The total number of transactions providing usable data is 1592, over the period 1982 to 2003 inclusive.[5] The bulk (78%) was from 1990 onwards. Of the overall total, 345 transactions

[4] We refer the reader to Appendix A in Adelman & Watkins (in press—MIT-CEEPR Working Paper, forthcoming) for more details.

[5] In Adelman and Watkins (1997) we showed data for 1979, 1980 and 1981. However, the meager number of observations and the unreliability of the results for these years led us to drop them this time around.

Table 1
Number of identified transactions

1	2	3	4	5	6	7	8	9	10
Year	All inclusive			Number of outliers			Excluding outliers		
	All types	Pure oil	Pure gas	All types	Pure oil	Pure gas	All types	Pure oil	Pure gas
All years	1592	345	435	106	32	26	1486	313	409
1982	14	1	0	1	0	0	13	1	0
1983	22	2	1	1	0	0	21	2	1
1984	34	8	1	3	1	0	31	7	1
1985	35	5	4	1	0	0	34	5	4
1986	27	3	3	2	0	0	25	3	3
1987	51	12	5	2	2	0	49	10	5
1988	66	14	9	2	1	0	64	13	9
1989	104	19	18	5	1	0	99	18	18
1990	160	38	29	9	3	2	151	35	27
1991	101	20	18	7	1	0	94	19	18
1992	92	20	20	6	2	2	86	18	18
1993	122	28	28	7	1	2	115	27	26
1994	98	17	33	6	2	2	92	15	31
1995	124	35	33	10	5	2	114	30	31
1996	100	31	31	6	1	2	94	30	29
1997	72	16	27	5	3	1	67	13	26
1998	91	19	45	8	3	3	83	16	42
1999	62	13	26	5	1	2	57	12	24
2000	70	15	28	4	1	2	66	14	26
2001	50	10	17	4	1	3	46	9	14
2002	57	14	36	8	3	4	49	11	32
2003	40	5	23	4	0	2	36	5	21

Outliers are defined as follows:

For pure transactions, a reserve price more than two standard deviations for that year.
For mixed transactions, a transaction value more than two standard deviations away from the fitted value.
Transactions of value less than \$0.55 per barrel of \$0.10 per mcf, or greater than \$27.50 per barrel of \$5 per mcf.

Source: The Scotia Group M&A Database, January 2004.

identified only oil reserves as sold (22%); 435 transactions only identified gas reserves (27%). We call these ‘pure’ oil and ‘pure’ gas transactions, respectively. All the other 812 transactions (51%) involved the joint sale of oil and gas reserves; we term them ‘mixed’ transactions.

2.2.1. Outliers

Unit values of reserves (the in situ price per barrel or per mcf) for the ‘pure’ transactions were simply the transaction value divided by the relevant oil or gas reserve. Certain values were unusually high or low in relation to average market values. It is probable that such transactions reflected special terms of sale such as “goodwill,” lack of information on the nature of the property exchanged, or even erroneous data. Inclusion of these transactions in the sample would distort the market conditions we are trying to discern.

Accordingly we eliminated all ‘pure’ transactions where the calculated reserve price was more than two standard deviations from the mean value for the relevant year. We also excluded any 'pure' values that appeared unreasonably low in an absolute sense: below 10 cents per mcf or 55 cents per barrel. Similarly, we excluded unreasonably 'high' values, values where the apparent unit reserve value exceeded \$5 per mcf or \$27.50 per barrel of reserve.[6]

The regression analysis pursued in Section 3 embraces both 'pure' transactions and 'mixed' transactions, i.e., those including both oil and natural gas reserves. Our criterion for elimination here was that the actual transaction value be more than two standard errors away from the fitted value obtained from the regression equation. We continue to eliminate any 'pure' observation identified as an outlier in the stand-alone analysis of 'pure' transactions even if not so identified in the regression. We also excluded from the regression 'high' and 'low' unit value observations, irrespective of the two standard deviation criterion.[7] Here mixed transactions were converted to gas equivalence using the 5.5 mcf/bbl conversion rule.

Hence, the outliers in the regression analysis consist of all observations, 'pure' and 'mixed', defined as outliers using the fitted value criterion; any pure transaction defined as an outlier in the independent analysis of pure observations, irrespective of whether it is defined as an outlier in the regression analysis; and any 'low' or 'high' valued observations not already identified as outliers under the standard error rule. In almost all cases, outliers identified in the 'pure' analysis turned out to be also identified as outliers in the regression analysis. A further comment on outliers, in the context of robust regression techniques, is made in Section 3.

The outliers listed in Table 1 (column 5) total 106 transactions. While the number of outliers is small–a mere 7% of the total observation set–they are extreme values. Hence their exclusion does materially affect the sample. The number of observations after exclusion of the outliers is shown in columns 8, 9 and 10, Table 1.

We found our outlier procedure useful as a sensing device, leading us to subject outlying observations to additional scrutiny. In some instances this resulted in our eliminating an observation from the data set entirely, for example where the transaction was revealed as including overseas properties, did not have sufficient segregation of assets acquired, expressed reserve quantities in 'barrels equivalence', or was part of a mega merger. More generally, an observation identified as an outlier was only discarded from the data set if there was an independent reason to consider it invalid, not because it was simply so many standard deviations from a fitted value.

2.2.2. Summary statistics

Summary statistics are shown in Table 2 for values of all transactions (excluding outliers) and display a considerable spread in annual mean values.[8] There is a pattern, however, with higher values congregating at the beginning and the end of the sample period, while

[6] The lower and upper limits for oil were simply the thermal equivalence of the natural gas values, using a conversion factor of 5.5 mcf/bbl.

[7] Most of these observations were identified as outliers under the two standard deviation test. However, the lower two standard deviation boundary value could be negative, precluding identification as outliers observations with unreasonably low unit values. Hence the need at least for a lower absolute value test.

[8] An even greater spread in mean values is displayed by transactions before adjustment for outliers, as might be expected.

Table 2
Summary statistics for transaction values, excluding outliers (millions of nominal $, where relevant)

1	2	3	4	5	6	7	8	9
Year	Mean	S.D.	Median	Coefficient of variation	Skewness	Kurtosis	Log normality	No. of observations
All years	47.4	90.4	15.0	1.72	2.87	12.58	–	1486
1982	61.2	63.2	32.0	1.03	0.76	1.90	Not rejected	13
1983	74.5	182.2	13.8	2.45	3.20	12.48	Not rejected	21
1984	320.2	1047.2	33.7	3.27	4.66	24.10	Not rejected	31
1985	80.5	161.2	16.8	2.00	2.97	11.02	Not rejected	34
1986	78.2	143.2	10.1	1.83	1.86	4.89	Not rejected	25
1987	19.8	35.8	6.0	1.81	2.81	10.23	Not rejected	49
1988	56.3	142.9	6.7	2.54	3.66	15.73	Not rejected	64
1989	28.3	59.7	8.0	2.11	4.99	34.37	Not rejected	99
1990	16.8	32.3	5.0	1.93	3.12	12.33	Not rejected	151
1991	13.5	22.6	5.0	1.67	2.82	11.39	Not rejected	94
1992	19.0	33.6	4.4	1.77	2.85	11.85	Not rejected	86
1993	20.4	31.8	7.0	1.56	2.77	11.32	Not rejected	115
1994	20.0	29.6	8.2	1.48	2.59	9.95	Not rejected	92
1995	19.1	31.2	8.0	1.64	2.89	11.29	Not rejected	114
1996	20.7	28.2	10.5	1.36	2.90	13.11	Not rejected	94
1997	85.5	120.8	25.1	1.41	1.72	5.39	Not rejected	67
1998	42.3	55.5	17.0	1.31	1.82	5.63	Not rejected	83
1999	22.4	24.0	13.7	1.07	1.61	5.16	Not rejected	57
2000	116.0	209.3	22.0	1.80	2.42	8.05	Not rejected	66
2001	101.0	217.2	32.2	2.15	4.76	28.23	Not rejected	46
2002	106.7	141.9	60.0	1.33	2.63	10.44	Not rejected	49
2003	119.9	112.5	95.5	0.94	0.87	2.72	Not rejected	36

The normality test used is Jarque–Bera; reject indicates that normality of the log distribution was rejected at 95% confidence level.
Source: The Scotia Group M&A Database, January 2004.

consistently lower mean transaction values prevailed over the interval 1989–1996, in part reflecting the larger number of observations in those years, which may better represent skewness towards smaller volumes in the underlying population of reserves (see below).

The distribution of transaction value observations for virtually all years is skewed to the left: smaller transaction values predominate. The medians are appreciably less than the means. Not surprisingly, normality is strongly rejected for each year.[9] But log normality would not be rejected for any year.[10] The coefficients of variation are quite erratic before 1988, but are more stable thereafter, at least until 1999. The distributions of *volumes* of oil and gas reserves sold are heavily skewed to observations with relatively small reserves.

We conclude that the statistical characteristics of the transaction data are in large measure stable across years. The distributions are typically skewed towards smaller transactions. Normality for the size distribution of transactions is rejected, whereas log

[9] The test used was Jarque–Bera.

[10] Although log normality is not rejected, it does not follow that it is the best-skewed distribution to represent the data. For example, in terms of North Sea data, Smith and Ward (1981) found that the log normal was not the preferred data generating process.

normality is not. Since the underlying volumetric size distribution of oil and gas reservoirs is heavily skewed–with log normality not rejected in virtually all years–the transaction data broadly represent the occurrence of the reserves in nature. To this extent, the data do not seem to constitute a biased sample from the underlying population.

3. Regression results

In this section, we use the transaction data discussed in Section 2 to estimate the price of oil and gas reserves. We report separately on values obtained from linear regressions of both types of transactions together ('mixed' and 'pure') and on values obtained from the simple division of 'pure' transaction values by corresponding individual reserve volumes. We also report on the results of some statistical tests and searches for relationships among possible transaction related variables. These include reserve-to-production ratios, reserves status (on production or not) and levels of field prices, all of which may have a systematic influence on reserve values. Finally, we illustrate how the estimates of reserve values can be used to measure company performance.

The estimates of the unit reserve values for a given year are from regression values of the actual transactions sales of oil and gas reserve properties during that year. These values reflect all information, expectations, forecasts, hunches, and mistakes of buyers, sellers, operators and investors.

The basic statistical method employed is least squares regression. Fortunately, there are enough transactions relating solely to oil reserves or solely to gas reserves ("pure oil" or "pure gas") to provide some kind of check on the regression results. Specifically, transaction values (in $millions) were regressed on the quantity of oil reserves (in millions of barrels) and on the quantity of natural gas reserves (in billions of cubic feet).

Conventional cash flow analysis indicates that a transaction value for the sale of oil and gas reserves would consist of the sum of the net present values of the expected flows of oil and gas production yielded by the property. This would suggest specifying value as a linear function of the respective reserves.[11] There is a question of whether the equation specification should include a cross-product term. Reservoir engineering provides little evidence of a systematic relation between oil and gas reserves underlying various properties.[12] Our data are in agreement: the simple correlation coefficients among oil and gas reserve transaction volumes for each year of our data set are typically low. Moreover, there is a basic logical objection: insertion of a cross-product term in the equation specification would make the estimated reserve price of oil conditional on a given volume of gas reserves, and vice versa. This would thwart one of the main objectives of our investigation, namely to estimate as best we can an unambiguous price of oil and gas reserves. For these reasons we rejected inclusion of a cross-product term in the equation specification.

[11] For discussion of this issue see Adelman and Watkins (1995, p. 666).

[12] If it did, aggregation of oil and gas reserves would be simple—gas reserves would be a function of oil reserves and vice versa. Either oil or gas reserves could be employed as a common numeraire.

Hence our basic regression equation is:

$$V = b_0 + b_1 R_o + b_2 R_g \quad (1)$$

where: V=transaction amount; R_o=volume of oil reserves; R_g=volume of natural gas reserves.

The observation set used in the regressions is for all transactions, mixed plus pure (those where only oil reserves or only gas reserves changed hands), with and without outliers (see Section 2 for discussion of outlier identification).[13]

Theoretically, a constant term in these regressions would be zero. No reserves sold, no value. We ran the regressions both suppressing and including a constant term. The latter may well attract noise in the data, detect systematic biases and indicate non-linearities. Also, a significant positive constant might be interpreted as affected by option values, fixed transaction costs, consistent goodwill and the like.[14] However, we retain a preference for the no-constant specification. And as will be seen, the constant term was insignificant in most cases.

The regressions with outliers excluded were run with corrections for heteroscedasticity. This increased the standard errors of the coefficients in all but some of the earlier years.

3.1. Results before exclusion of outliers

There is a great deal of variability in both the oil and gas reserve coefficients, representing the price of reserves in barrels or mcfs, respectively.[15] This in part reflects the retention of outliers. The price of *oil* reserves shows no obvious overall pattern over time, and its fluctuations bear only a scant relationship to shifts in field prices—as shown by later analysis. In all years, the oil reserve coefficients were statistically significant, usually strongly so.

The price of *natural gas* reserves represented by the regression coefficients also shows noticeable fluctuations year over year, fluctuations that again do not seem to be well correlated with changes in field prices (see later analysis). Except for 1982, all the gas reserve coefficients are strongly significant.

The results with inclusion of a constant term in the regression equation show the constant as statistically significant in only 3 years (1988, 1990, 1996). Hence the estimates of reserve prices results do not noticeably differ from those with the constant suppressed.

Reserve values consist of present values of expected field prices (output prices), net of expected extraction costs. As an empirical matter, reserve values are influenced by current and field prices, which in effect are an imperfect approximation to expected field prices.

[13] We ran Box–Cox tests on functional form. The results were inconclusive—no convincing evidence emerged favoring the linear or log linear forms; a reciprocal relationship was strongly rejected. Our preference remained for a straightforward linear function, for economic reasons: we wanted to estimate unit prices.

[14] The "option value" of some of a reserve denotes an underground formation with zero or negative value as currently known. Its positive value consists in the hope or expectation that its future volume will be greater than current, or its development costs lower, or prices higher. The best explanation is in Paddock et al. (1988).

[15] For detailed results, see Appendix B, Adelman & Watkins (in press—MIT-CEEPR Working Paper, forthcoming).

We have a check on the OLS regression estimates, by comparison with the 'pure oil' and 'pure gas' transaction values.[16] To derive aggregate 'pure' values, the barrels in each transaction, for a given year, weight the pure oil value observations volumetrically. This is equivalent to summing the value of all pure transactions in a given year and dividing by the total volumes of oil or gas reserves sold, respectively. The ratios of the oil reserve coefficients from the regressions to the 'pure' oil unit values differ markedly. There is little consistency, except that the regression coefficients are lower than the 'pure' oil transactions in about half the sample, and for the period 1998–2003 the coefficients exceeded the 'pure' values. Only in eight of the 22 years (1982, 1987, 1988, 1989, 1990, 1995, 1998, 2000) are the ratios within 10% of unity.[17]

In the case of natural gas, again there is a large spread in the ratios of the regression values to the 'pure' values. In only 9 years–1986, 1987, 1989, and 1998 through 2003– were the ratios within 10% of unity. In contrast to oil, in the majority of years the regression coefficients exceeded the 'pure' values.

We conclude that the reserve values derived from the overall sample of transactions differ appreciably in most years from the 'pure' transaction sample. However, in many years the number of 'pure' observations is small, contributing to variability between the two sets of reserve values.

3.2. Results excluding outliers

Table 3 lists our estimates of reserve prices when outliers are excluded, and the constant term suppressed. With the exception of 1985 and 2000, all the oil reserve coefficients are strongly significant. Their amplitude of variation, while large, is less than when the outliers are included, as would be expected. Much the same comment applies to the natural gas reserve coefficients, and no statistically insignificant values were recorded except for 1982. Overall, the gas coefficients are more stable over time than those for oil.

Results with an intercept showed a similar pattern to those without it. The constant term was significant in 7 years (1983, 1984, 1985, 1987, 1998, 2000 and 2001).

The oil reserve coefficients from the regression are plotted in Fig. 1; those for natural gas are plotted in Fig. 2. The plots are for the case excluding outliers and without an intercept. The respective sets of reserve values are also shown adjusted for inflation after applying the U.S. producer price index (2003 = 1.0).[18]

While there are no apparent *overall* trends in either set of reserve prices in money-of-the-day terms, there is a noteworthy increase in oil reserve prices since year 2000, and for natural gas since 1998 (with an unusual blip in 2001). The oil reserve price in 2003 is marginally higher than the previous peak in 1985. In real terms, the 2003 oil price is around 20% below the 1985 peak. The 2003 natural gas reserve price remains below real levels of the mid-1980s (excepting 2001).

[16] Recall that the pure values are calculated by simply dividing the adjusted transaction value by the relevant volume of oil and gas reserves.

[17] These results are notwithstanding the fact that regression data include the 'pure' oil cases (see earlier).

[18] Adjustment using the U.S. GDP or CPI index results in higher real values than under the PPI.

Table 3
Regression results for all transactions (no constant), excluding outliers (with robust standard errors, rather than OLS standard errors)

1 Year	2 No. of observations	3 Oil coefficient ($/bbl)	4 t-stat	5 Gas coefficient ($/mcf)	6 t-stat	7 Adjusted R^2
1982	13	7.13	9.18	0.36	1.26	0.76
1983	21	3.37	39.87	0.64	58.92	0.99
1984	31	6.95	177.40	0.86	173.62	0.90
1985	34	7.74	1.66	0.52	1.05	0.89
1986	25	5.10	6.66	0.96	20.63	0.99
1987	49	4.40	6.48	1.02	6.96	0.92
1988	64	5.69	22.87	0.99	32.97	0.98
1989	99	4.61	3.56	0.88	5.75	0.82
1990	151	3.64	9.07	0.90	15.61	0.94
1991	94	4.44	12.36	0.87	29.63	0.96
1992	86	4.14	6.95	0.82	11.43	0.89
1993	115	3.54	15.00	0.87	13.45	0.94
1994	92	2.90	4.32	0.77	19.58	0.91
1995	114	3.81	16.85	0.60	9.93	0.95
1996	94	3.67	3.98	0.69	17.76	0.86
1997	67	5.01	14.24	0.93	15.52	0.92
1998	83	2.85	3.15	0.62	6.33	0.81
1999	57	3.59	6.31	0.67	7.39	0.88
2000	66	3.55	1.96	0.75	6.17	0.74
2001	46	5.75	10.96	1.45	19.02	0.97
2002	49	5.74	10.20	0.88	9.69	0.95
2003	36	8.17	17.81	1.19	18.52	0.97

Source: The Scotia Group M&A Database, January 2004.

What impact does inclusion of a constant in the regression equation have on the regression coefficients? For oil, only in 3 years (1982, 1998 and 2000) did the constant affect the regression coefficient by more than 10%. For natural gas, only in 1982 and 1985 did the impact of the constant on reserve values exceed 10%.

Table 4 summarizes the impact of the exclusion of outliers on the reserve coefficients. The ratio of the oil and gas regression coefficients with and without the outliers is calculated in the no constant case. The impact of suppressing the outliers is considerable. And this holds in the case of both oil and gas.

Another approach to the issue of unusual observations is to apply robust regression techniques.[19] As an example, 'M Class' estimators and 'Least Trimmed Square' estimators were calculated for our total set of observations for the year 1996. The results both confirmed the presence of unusual, influential observations and yielded estimated coefficients similar to ours after we excluded outliers. While this analysis was only confined to 1 year, it suggests our ad hoc rules for identifying outliers, described in Section 2, are broadly congruent with those from a robust regression approach.

[19] We are grateful to Adonis Yatchew, University of Toronto, for this suggestion.

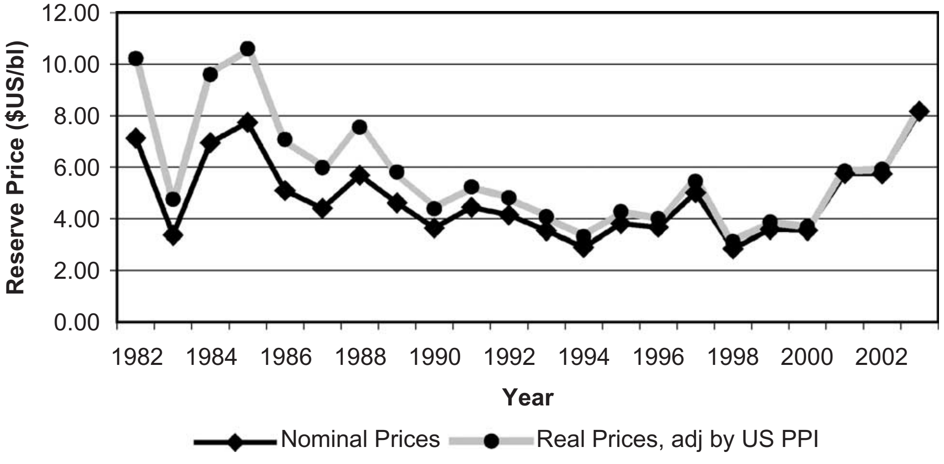

Fig. 1. Estimates of U.S. oil reserve prices, 1982–2003.

When the oil regression values (no constant) are compared with the weighted pure oil case values (outliers excluded in both instances) no clear pattern over time emerges. The number of years when the ratio is within 10% of unity is 11, half of the total. Much the same conclusion applies to natural gas. The number of years when the ratio is within 10% of unity is 9, of which 4 consist of the last 4 years, 2000–2003.

3.3. Influence of reserves' status

Information was available for certain transactions that distinguished between those where reserves were on production and those where they were seemingly fallow, wholly or partly. In the latter case the properties may include prospective reserves normally classified as proved undeveloped, developed but not on production, probable or possible.

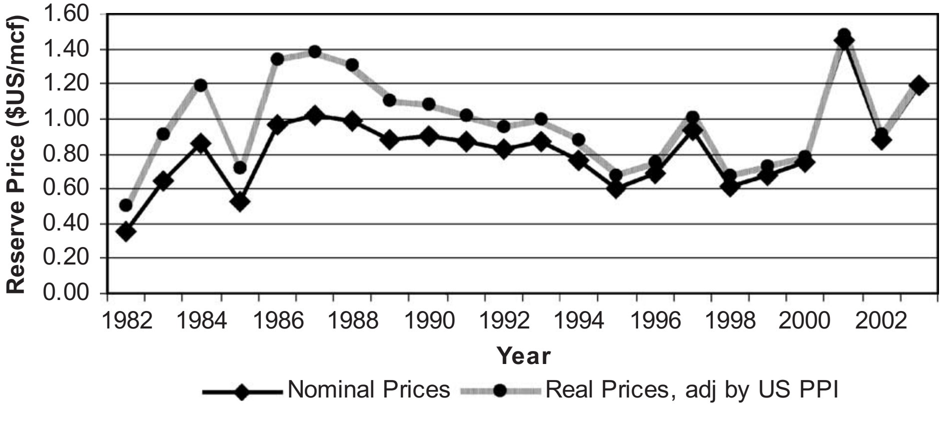

Fig. 2. Estimates of U.S. natural gas reserve prices, 1982–2003.

Table 4
Effect of outliers on reserve coefficients (no constant)

1	2	3	4	5	6	7
Year	Oil coefficient ($/bbl)			Gas coefficient ($/mcf)		
	All data	Excluding outliers	Ratio 2/3	All data	Excluding outliers	Ratio 5/6
1982	7.59	7.13	1.06	0.35	0.36	0.97
1983	4.35	3.37	1.29	0.65	0.64	1.01
1984	3.71	6.95	0.53	1.02	0.86	1.18
1985	5.62	7.74	0.73	0.73	0.52	1.40
1986	2.12	5.10	0.42	0.97	0.96	1.01
1987	5.60	4.40	1.27	0.94	1.02	0.91
1988	6.07	5.69	1.07	1.20	0.99	1.22
1989	4.60	4.61	1.00	1.21	0.88	1.38
1990	4.18	3.64	1.15	0.48	0.90	0.53
1991	3.35	4.44	0.76	1.16	0.87	1.33
1992	6.34	4.14	1.53	0.75	0.82	0.91
1993	2.60	3.54	0.73	1.49	0.87	1.71
1994	5.59	2.90	1.93	0.74	0.77	0.96
1995	3.16	3.81	0.83	0.88	0.60	1.46
1996	6.98	3.67	1.90	0.95	0.69	1.39
1997	2.88	5.01	0.58	1.13	0.93	1.22
1998	3.53	2.85	1.24	0.76	0.62	1.23
1999	4.97	3.59	1.39	0.86	0.67	1.28
2000	4.21	3.55	1.19	0.75	0.75	1.00
2001	6.40	5.75	1.11	1.32	1.45	0.91
2002	6.49	5.74	1.13	1.21	0.88	1.37
2003	9.87	8.17	1.21	1.12	1.19	0.94

Source: The Scotia Group M&A Database, January 2004.

Other things equal, the in situ reserve values for reserves on production would be expected to exceed those for dormant reserves. The theoretical margin between two identical properties, one on production, the other not developed, would be the development cost per unit of reserve, in the absence of any option value for the undeveloped reserve.

We tested the proposition of such differential values using our database of 1486 transactions, of which 1010 observations related to properties seemingly not on production.[20] We caution lack of information may have exaggerated the number of observations in this category.

Specifically, we performed the following regression:

$$\text{adjprice} = \left[a_1^{\text{o}} + a_2^{\text{o}} D_{\text{o}}\right] R_{\text{o}} + \left[a_1^{\text{g}} + a_2^{\text{g}} D_{\text{g}}\right] R_{\text{g}} \qquad (2)$$

where: adjprice is the transaction price (after elimination of non reserve assets) as previously used; the 'o' superscript denotes oil; the 'g' superscript denotes gas; a_1 and a_2

[20] This set includes observations where oil reserves are not on production, observations where gas reserves are not on production, and where both were dormant.

are the two coefficients for each reserve being tested; R denotes reserves sold; D denotes a dummy variable for reserves on production.

A priori, we expect both the a_1 and a_2 coefficients to be positive: reserves already producing would be expected to be worth more than those lying fallow.

The results are shown in Table 5 (excluding outliers, no constant). For oil, the first coefficient is positive as expected (except for 1985). However, 13 of the second coefficients are negative, although only 2 of these are statistically significant. Of the 8 positive second coefficient values, 4 are significant. For natural gas, all the first coefficients are positive, but 12 second coefficients are negative, of which 6 are statistically significant; only 2 of the positive second coefficients are significant.

We treat these findings as broadly confirming that the sales value of oil reserves on production exceeds that where developed properties are either not producing, or are only partly on production. The results for natural gas are murky.

3.4. Influence of the R/P ratio

A factor that can be expected to influence reserve values is the rate at which reserves are produced. Evidence for such an effect is likely confined to cross-sectional data. The shift in time series data for R/P ratios is too gradual to reveal impacts. United States (remaining) reserves to production ratios for oil are quite stable; those for gas have shown some tendency to fall.[21]

The years during which we had an appreciable number of transactions containing R/P ratio information were confined to 1989, 1990 and 1992 to 2003, inclusive. To test whether the R/P ratio affects the transaction price we performed the following regression:

$$\text{adjprice} = \left[a_1^{\text{o}} + a_2^{\text{o}} H_{\text{o}}\right] R_{\text{o}} + \left[a_1^{\text{g}} + a_2^{\text{g}} H_{\text{g}}\right] R_{\text{g}} \qquad (3)$$

where: adjprice is the transaction price (after elimination of non reserve assets); the 'o' superscript denotes oil; the 'g' superscript denotes gas; a_1 and a_2 are the two coefficients for each reserve being tested; R denotes reserves sold; H denotes the R/P ratio.

The regression was run without a constant term. The results are shown in Table 6.

The greater the R/P ratio, the lower the rate of production. The lower the rate of production in relation to reserves, the lower the expected price of reserves, other things equal. Hence the expected sign of the a_2 coefficient attaching to the H variable (the R/P ratio) would be negative.

In the case of oil the a_2 coefficient is negative in 12 of the 13 years for which we had data; it was significant in 4 of the 12 cases. In these 4 cases, the coefficient shows a great degree of variation, from −\$1.64/bbl in 1989 to −\$0.01/bbl in 1996. In both years in which the coefficient was positive, it was insignificant.

In the case of gas, a_2 is negative in all years but one (and here it was insignificant). Of the 12 years in which it is negative, it was significant in 8 instances. The absolute value of the incremental coefficient is less than 10 cents/mcf in all years except 2001.

[21] See Table C-1, Adelman & Watkins (in press—MIT-CEEPR Working Paper, forthcoming).

Table 5
Regression results for transactions with information on reserve status (no constant), excluding outliers

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Year	Oil ($/bbl)				Natural gas ($/mcf)				Adjusted R^2	Total observations	No. of observations		
	a_1	t-stat	a_2	t-stat	a_1	t-stat	a_2	t-stat			No oil or gas produced	No oil produced	No gas produced
1982	7.13	4.02	–	–	0.36	1.54	–	–	0.72	13	13	13	13
1983	5.84	0.10	−2.47	−0.04	0.64	25.51	–	–	0.99	21	20	20	21
1984	3.50	4.72	3.47	4.71	2.05	0.47	−0.94	−0.22	0.99	31	31	31	33
1985	−3.28	−0.04	12.46	0.16	1.38	2.51	−1.05	−1.76	0.89	34	32	32	32
1986	6.94	1.07	−1.82	−0.28	1.19	3.85	−0.24	−0.76	0.99	25	24	24	25
1987	4.44	1.06	−0.68	−0.16	0.80	3.83	0.33	1.42	0.92	49	41	41	44
1988	5.50	41.66	2.76	6.28	1.02	46.41	−0.25	−5.45	0.99	64	55	55	56
1989	5.15	2.94	−0.02	−0.01	1.02	16.29	−0.50	−4.62	0.85	99	85	87	89
1990	4.58	1.33	−0.96	−0.28	0.82	14.41	0.10	1.49	0.94	151	142	146	149
1991	4.33	18.84	0.47	1.09	0.79	7.22	0.08	0.70	0.96	94	80	81	89
1992	4.18	10.23	0.08	0.13	0.78	9.34	0.11	0.90	0.89	86	57	63	67
1993	3.57	12.15	−0.57	−0.97	0.81	29.57	0.19	3.91	0.95	115	74	84	81
1994	3.14	12.81	−0.64	−1.38	0.79	24.20	−0.26	−2.38	0.91	92	53	63	55
1995	3.93	28.77	−1.20	−2.63	0.66	22.35	−0.07	−1.76	0.95	114	78	90	85
1996	4.01	14.34	−1.58	−2.53	0.74	16.77	−0.15	−1.83	0.87	94	57	67	63
1997	3.56	4.45	1.86	2.09	0.90	11.46	0.07	0.70	0.93	67	46	53	53
1998	1.81	5.21	3.01	5.00	0.80	13.77	−0.27	−3.85	0.87	83	46	68	54
1999	3.79	8.19	−0.56	−0.30	0.58	13.11	0.25	3.50	0.90	57	26	43	30
2000	6.02	3.10	−3.32	−1.48	0.77	11.06	−0.10	−0.83	0.74	66	29	50	34
2001	5.43	7.72	−0.34	−0.27	1.38	14.71	0.22	1.25	0.97	46	18	31	25
2002	5.55	9.19	0.23	0.34	1.06	9.48	−0.21	−1.77	0.95	49	27	47	36
2003	8.37	11.55	−3.89	−1.38	1.24	29.31	−0.29	−2.69	0.97	36	29	28	11

(–) Insufficient data points.
Reserve status—whether reserves are on production or not.
Equation specification:

$$\text{adjprice} = \left[a_1^{\text{o}} + a_2^{\text{o}} D_{\text{o}}\right] R_{\text{o}} + \left[a_1^{\text{g}} + a_2^{\text{g}} D_{\text{g}}\right] R_{\text{g}}$$

where: adjprice is transaction price (after elimination of non reserve assets); the ‘o’ superscript denotes oil; the ‘g’ superscript denotes gas; a_1 and a_2 are the two coefficients for each reserve being tested; R denotes reserves sold; D denotes dummy variable for reserves on production.

Table 6
Regression results for transactions with information on R/P ratios (no constant), excluding outliers

1	2	3	4	5	6	7	8	9	10	11
Year	Oil ($/bbl)				Natural gas ($/mcf)				Adjusted R^2	No. of observations
	a_1	t-stat	a_2	t-stat	a_1	t-stat	a_2	t-stat		
1982	–	–	–	–	–	–	–	–	–	–
1983	–	–	–	–	–	–	–	–	–	–
1984	–	–	–	–	–	–	–	–	–	–
1985	–	–	–	–	–	–	–	–	–	–
1986	–	–	–	–	–	–	–	–	–	–
1987	–	–	–	–	–	–	–	–	–	–
1988	–	–	–	–	–	–	–	–	–	–
1989	11.00	3.35	−1.64	−2.00	0.80	4.30	0.03	1.17	0.97	17
1990	4.95	2.57	−0.39	−0.61	1.08	24.70	−0.04	−6.22	0.99	14
1991	–	–	–	–	–	–	–	–	–	–
1992	3.81	4.40	0.07	0.33	1.05	7.29	−0.08	−2.37	0.93	32
1993	3.85	10.11	−0.06	−1.15	1.21	20.16	−0.09	−7.22	0.97	46
1994	2.31	3.44	0.22	1.43	1.08	7.16	−0.07	−1.97	0.93	42
1995	5.00	7.57	−0.29	−1.66	0.72	8.49	−0.01	−0.77	0.97	42
1996	4.55	11.16	−0.01	−2.95	0.86	5.72	−0.02	−0.91	0.89	41
1997	5.00	5.35	−0.29	−1.73	0.93	25.56	0.00	−0.28	0.98	24
1998	5.68	8.14	−0.29	−5.62	1.06	13.96	−0.04	−2.97	0.95	42
1999	4.71	2.30	−0.16	−0.46	0.58	3.20	0.00	−0.03	0.86	32
2000	11.53	3.15	−0.66	−1.44	0.95	10.68	−0.03	−2.92	0.88	37
2001	5.19	3.05	−0.07	−0.22	2.20	11.66	−0.16	−5.21	0.96	28
2002	10.33	7.96	−0.99	−3.75	1.45	8.31	−0.08	−2.44	0.97	27
2003	9.44	4.12	−0.51	−0.54	1.23	26.97	0.00	0.21	0.97	29

(–) Insufficient data points.
R/P ratio is the ratio of remaining reserves to annual production.
Equation specification:

$$\text{adjprice} = \left[a_1^{\text{o}} + a_2^{\text{o}} H_0\right] R_0 + \left[a_1^{\text{g}} + a_2^{\text{g}} H_{\text{g}}\right] R_{\text{g}}$$

where: adjprice is transaction price (after elimination of non reserve assets); the ‘o’ superscript denotes oil; the ‘g’ superscript denotes gas; a_1 and a_2 are the two coefficients for each reserve being tested; R denotes reserves sold; H denotes the R/P ratio.

Our broad conclusion is that the transaction data do support the proposition that reserve prices would be inversely related to R/P ratios—and especially so for natural gas.[22]

In summary: the impact on reserve prices of the two types of transactions discussed above–of whether production is taking place and of the rate of production–has the following implication. Unless the mix of transactions by these categories is reasonably constant, some of the variation in estimates of reserve prices among years will reflect compositional shifts in transaction types. Hence caution has to be exercised in any interpretation of temporal changes in estimated reserve prices. This seems to apply to a greater degree to natural gas than to oil reserve prices.[23]

[22] The Hotelling Valuation Principle (HVP) would admit no such influence of production rates on reserve values. Also, see Adelman and Watkins (2003, Section IV).

[23] Changes in the regional mix of transactions is another source of variation.

Table 7
Regression results: reserve prices and field prices

1	2	3	4	5	6	7
	Constant	*t*-stat	Coefficients	*t*-stat	Adjusted R^2	No. of observations
Reserve prices against field prices						
Oil contemporary price ($/bbl)	1.75	1.73	0.16	3.13	0.30	22
Gas contemporary price ($/mcf)	0.57	4.26	0.11	2.03	0.13	22
Oil 1 Period lag price ($/bbl)	1.74	1.69	0.16	2.98	0.28	21
Gas 1 Period lag price ($/mcf)	0.59	3.80	0.12	1.80	0.10	21
Oil 2 Period lag price ($/bbl)	1.78	1.73	0.16	3.01	0.30	20
Gas 2 Period lag price ($/mcf)	0.69	4.22	0.08	1.09	0.01	20
Reserve prices against first differences in field prices						
Oil contemporary price ($/bbl)	4.69	13.93	−0.02	−0.29	−0.05	21
Gas contemporary price ($/mcf)	0.84	18.12	0.08	1.16	0.02	21
Oil 1 Period lag price ($/bbl)	4.77	13.76	0.03	0.46	−0.04	20
Gas 1 Period lag price ($/mcf)	0.86	18.21	0.09	0.99	0.00	20
Oil 2 Period lag price ($/bbl)	4.64	13.42	−0.02	−0.31	−0.05	19
Gas 2 Period lag price ($/mcf)	0.86	16.56	−0.01	−0.12	−0.06	19

3.5. Relationship between reserve regression coefficients and field prices

Expected field prices (output prices) are an important determinant of reserve values, values that are influenced by current and previous field prices. We made some simple tests to see whether the annual estimates of oil and gas reserve prices calculated from the regressions displayed any obvious relationship with current and lagged field prices. We confined the tests to a simple linear regression of in-ground reserve prices, represented by our estimated oil and gas regression coefficients on field prices. We note that since reserve prices are influenced by field price expectations it is by no means clear in theory that a zero current or lagged field price would indicate zero reserve prices. Hence reserve prices could be positive even if field prices were zero. There is, then, a preference for including a constant term in the equation specification.[24]

The regression results for both oil and natural gas are shown in the upper panel of Table 7 for the two sets of regressions where the reserve price was regressed on each of contemporary field prices, prices lagged 1 year, and prices lagged 2 years. For the oil equations the intercept is positive and significant at the 10% level, but not at the 5% level. For the gas equation the intercept is positive and significant at the 5% level. Oil reserve prices are positively (and significantly) related to field prices, whether contemporary or lagged 1 or 2 years; the results suggest about 16% of any increase in field prices would be reflected in reserve prices. But the degree of linear fit of the three oil equations is modest. Gas reserve prices are also positively related to field prices, and two of the three coefficients are statistically significant; however, the degree of linear fit is trivial.

We also subjected the time series of reserve and field prices to stationarity tests. Stationarity was not rejected for the reserve price series, but was rejected for the field

[24] For the field price series used, see Table C-4, Adelman and Watkins (2003).

price series. Stationarity was not rejected for the residual terms of the equation results shown in the upper panel of Table 7; nor was it rejected for the first differences of the respective series in field prices. Thus the regressions are of $I(0)$ variables on $I(1)$ variables and result in $I(0)$ residual terms. The stationarity tests used a 5% level of significance throughout.

The fact that field prices were found to be I(1) while reserve prices were I(0) encouraged regressing reserve prices on the first differences of field prices, since both variables then would be I(0). The results are shown in the lower panel of Table 7. A fit is absent and coefficients for field price differences are all insignificant.[25] The constant term roughly picks up the average value of the respective reserve price series, which is consistent with what one anticipates for expected reserve prices when field prices are constant (first differences are zero). Overall, we find first differences in field prices do not have a material impact on reserve prices.

3.6. Reserve prices and company performance

Differences between the actual expenditures incurred by a company and those implicit in using the reserve prices generated from industry wide data will indicate the extent to which a company over or under performed in relation to the market. For example, suppose in year 2002 a company spent \$500 million in acquiring 100 million barrels of oil and 100 billion cubic feet of natural gas. Reserve prices for that year are \$5.74 per barrel and \$0.88 per mcf (see Table 3). At these prices, the estimated market value of the company's transaction would be \$574 million for the oil and \$88 million for the gas, a total of \$662 million. In this example, then, the company seemingly would have outperformed the market to the tune of \$162 million, or about 32%.

The reserve prices are subject to uncertainty. Two standard deviations either side of the point estimates cited above yield a spread in values for oil of \$4.58 to \$6.80 per barrel, for gas \$0.70 to \$1.06 per mcf.[26] At the lower price bounds the imputed value of the transaction would be \$528 million, and the company would still have outperformed the market by \$28 million, or some 5%. At the upper bound, the corresponding figures would be \$786 million, \$286 million and 57%.

4. Concluding remarks

The results of this research paper are of interest in several ways.

Reserve value embraces (net) price forecasts over the life of the reserve. This is because it mainly reflects the net present value of all the production expected. The appraisal is made by a team of engineers, geologists, bankers, economists and investors. Their forecasts may be wrong, but the values at which reserves change hands merit serious attention.

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[25] The expected sign of the coefficient is ambiguous. For example, a positive price change might indicate a peak, depressing price expectations embedded in reserve values, and resulting in a negative coefficient; or it might indicate further price increases are on the way, resulting in a positive coefficient.

[26] For standard errors of the coefficients, see Table 3.

The difference between the value of existing reserves on production and the cost of finding and developing additional reserves is the governor of investment. The value: cost comparison is a clue to whether oil or gas reserve additions will be expected to increase or decrease.

Oil and gas reserve values must be separately calculated. Barrels of "oil equivalent" are artifacts. Our research broadly confirms price and production data, and industry opinion: the oil and gas industries at least until very recently have been on a different track.

Oil reserve values show no overall secular trend, 1982–2003, sometimes falling, sometimes rising, as they have recently—but to levels in 2003 only marginally higher than the previous peak in money-of-the-day terms; in real terms the estimated 2003 reserve price is 20% below the 1985 peak. Movements in the oil reserve price reflect changing perceptions about the world oil market, not the U.S. domestic market, since no separate U.S. domestic market exists for crude oil. Since year 2000, reserve prices have risen as field prices used by companies for planning purposes have registered OPEC's ability to keep prices comfortably above $20/bbl.[27]

Natural gas reserve prices tended to fall gradually, from 1984 to 1995, as deregulation became pervasive; since then there has been an erratic tendency to rise, indicating nascent tighter supply conditions.

The national income needs to be adjusted for reserve accumulation or attrition. Our measures are based on the premise that reserves are created and consumed like all other capital assets. There is little support for the theory that minerals are somehow unique, and that a unit produced today ineluctably means one less produced at some future date, except in a very elementary sense. Future reserves will be determined by future technology and costs on the one side, and future demands on the other.

We believe our estimates of reserve values could be improved in several ways. First, as always it would be better to have more reserve transaction observations, and better information to "clean out" non-reserve assets more precisely. Second, there seems to be significant variation in reserve values according to reserve/production ratios, whether reserves are fallow, and so forth. Normalization for these variations would improve the consistency of estimates over time. Third, we would prefer to have information on the extent to which reserve values might incorporate option values, 'good will' and the like. Fourth, estimation of unit development costs would enable us to infer finding costs by deduction of development costs from prices of developed reserves.

Measuring the capital costs of newly created reserves is a problem we have barely touched. Depending on the state of knowledge, they could be rising, falling, or stable. So far as we can discern, North American natural gas reserve prices and marginal costs have been relatively stable until recently, while North American oil production has been gradually undermined by its rising costs in the face of quite stable worldwide costs.

[27] For discussion of price expectations embedded in the oil reserve price series in relation to the world oil market, see Adelman and Watkins (2003, p. 33).

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