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The Pricing of Oil and Gas: Some Further Results

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ABSTRACT

The Hotelling Valuation Principle (HVP) implies that the unit value of an exhaustible natural resource can be written as a function of its current price, net of extraction costs; other variables such as interest rates have no additional explanatory power. The results of earlier tests using data from 1979–1981 strongly support the HVP. This paper presents a series of follow-up tests using time-series cross-section data covering the period August 1981 to December 1983. Because the variance of petroleum prices in this period was substantially less than in the earlier period, the follow-up sample proved generally noninformative. The sample also contains some observations on oil and gas royalty trusts. Tests of the HVP using these trust data yielded generally satisfactory results, although—given the limited sample size—the results must be viewed with caution.

THE PURPOSE OF THIS paper is to present follow-up tests of the Hotelling Valuation Principle (HVP) for exhaustible resources. The HVP and the earlier tests are described in detail in an earlier paper (Miller and Upton [5]), and we will limit ourselves here to a brief summary.

The principle that the unit price of an exhaustible natural resource (less the marginal cost of extraction) will tend to rise at the rate of interest was first stated by Harold Hotelling [2]. It follows from intertemporal profit maximization on the part of a price-taking owner of an exhaustible natural resource: if the unit price of resources, net of extraction costs, is expected to rise by less than the rate of interest, why not extract it now; and if it will rise by more, why extract any today? The Hotelling Principle has become the standard paradigm for natural resource economics, although perhaps more from the absence of any viable alternative than from strong empirical validation. Earlier tests of the Hotelling Principle, generally based on time series of resource prices, have yet to provide convincing support.

I. The Hotelling Valuation Principle

We test the Hotelling Principle in another way, by considering one of its implications, which we call the Hotelling Valuation Principle. The HVP implies that the unit value of any exhaustible resource equals its current price, net of extraction costs. To see why, consider in its most simple form the problem confronting a profit-maximizing, price-taking owner of an exhaustible resource. (More general derivations are given by Miller and Upton [5], Pindyck [6], and

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Sundaresan [7]). Let $q_0, q_1, \cdots, q_N$ be the amount of the resource extracted at time $t = 0, 1, \cdots, N$; for simplicity, unit extraction costs are initially taken to be a constant c_0. The discounted present value of profits is then

$$V_0 = \textstyle\sum_{t=0}^{N} (p_t - c_0)q_t/(1 + r)^t \tag{1}$$

where p_t is the exogenously determined market price of output at time t, and r is the rate of interest (again assumed known and constant over time). V_0 is maximized subject to the constraint

$$\textstyle\sum_{t=0}^{N} q_t \leq R_0, \tag{2}$$

where R_0 are total reserves. The first-order condition for profit maximization in any period is

$$(p_t - c_0)/(1 + r)^t = \mu, \quad t = 0, \cdots, N, \tag{3}$$

where μ is the Lagrangian multiplier on the constraint (2). That is, the present value of the net unit price of output must be the same regardless of when it is produced. This equation leads directly to the familiar Hotelling Pricing Principle:

$$(p_t - c_0) = (p_0 - c_0)(1 + r)^t, \quad t = 0, \cdots, N, \tag{4}$$

and substitution of (4) into the valuation formula (1) leads directly to the HVP; viz,

$$V_0 = (p_0 - c_0) \textstyle\sum_{t=0}^{N} q_t = (p_0 - c_0)R_0. \tag{5}$$

II. The Test

When we generalize the extraction cost function to allow costs in period t to be a function $C(q_t, Q_t)$ of both q_t, the rate of extraction and $Q_t = \sum_{s=0}^{t} q_5$, the cumulative level of extraction, both (4) and (5) become more complicated. But we can show that the unit value of an exhaustible natural resource can be written

$$(V/R) = a + b(p_0 - c_0), \tag{5'}$$

where $p_0 - c_0$ represents the current price, net of average extraction cost. As to coefficients a and b, the HVP implies that a should generally be negative, and b should be "one or a little less," with the "little less" being an allowance for tax effects. The HVP further implies that other variables such as interest rates have no additional explanatory power.

III. Data Sources

Our test of the HVP thus comes down to estimating, both across companies and over time, the relation between market prices for exhaustible resources and their current net spot prices. In the case of the oil and gas industry, these data are readily available. In 1978, the SEC required that oil and gas companies publish annually reserve estimates as well as current (net) spot prices. For companies whose stock is publicly traded, current stock prices provide—after appropriate adjustments for liabilities and other assets—the market's valuation of the oil and gas reserves.

IV. Previous Work

Table I gives a quick summary of the key results we obtained with the first pooled time-series cross-section data set, based on observations from December 1979 to August 1981. The basic regression (row 1) is that of VALUE, the market value of oil and gas reserves, against HOTEL, the current margin on oil and gas sales. (The companies in our sample have both oil and gas reserves: HOTEL is a weighted average of the oil and gas margins, with the weights proportional to the ratio of BTU equivalent oil and gas reserves). The results are consistent with the HVP. The coefficient on HOTEL is 0.910 with a standard error of 0.114. It is thus in close agreement with the predicted "one or a bit less." The negative constant is also consistent with the HVP. The R^2 of 0.4 indicates that the independent variable HOTEL explains a substantial proportion of the intercompany, intertemporal variations in the market valuation of oil and gas reserves. As is also clear from the scatter plot, shown in Figure 1, the relation between VALUE and HOTEL is pervasive, and not attributable to a few observations.

The rest of Table I presents some decomposition tests where HOTEL is broken down in various ways into its various components. These provide strong tests of the restrictions implied by the HVP. Row (2) shows the effect of breaking HOTEL down into its OIL and GAS pieces. The coefficients are approximately equal, and there is no significant drop in explanatory power as a result of the decomposition. Similar decompositions of HOTEL into its price and cost components (row 3) and into the separate price and cost components for oil and gas (row 4) should—and do—yield results consistent with the basic regression. The coefficients all essentially equal a "little less" than one (or, in the case of the coefficients on cost terms, minus one); F tests indicate that the restrictions of equal coefficients embodied in the regression in row 1 cannot be rejected at conventional significance levels.

Other diagnostic tests, reported in our earlier paper, yielded results strongly consistent with the HVP. The one test that we could not conduct—for obvious reasons—was to see if the results continued to hold when we extended the data set.

V. New Results

We now have a second set of time-series cross-section data covering the period August 1981 to December 1983. The scatter plot of VALUE versus HOTEL for these observations, given in Figure 2, continues to show a pervasive linear relation between VALUE and HOTEL. This relation is confirmed when we turn to Table II, which parallels Table I. The differences between the two sets of results are seen by considering the basic regression (row 1). While there continues to be a relation between VALUE and HOTEL, the R^2 drops substantially from 0.4 to 0.15: the constant term of the regression—although still negative—is now much

Table I

Basic Regressions—First Data Set

Regression	Constant	HOTEL	OIL	GAS	OILP	OILC	GASP	GASC	Prices	Costs	R^2	σ_ε
(1)	−2.240	0.910									0.408	3.187
	(1.035)	(0.114)										
(2)	−3.078		0.844	1.134							0.426	3.155
	(1.138)		(0.120)	(0.174)								
(3)	−2.233								0.982	−1.117	0.414	3.188
	(1.035)								(0.137)	(0.244)		
(4)	−3.469				0.944	−1.041	1.088	−0.836			0.433	3.174
	(1.268)				(0.177)	(0.320)	(0.184)	(0.437)				

Notes: Dependent variable—market value of oil and gas/barrel equivalent of oil and gas reserves ($n = 94$). Standard errors are in parentheses.

Source: Merton H. Miller and Charles W. Upton. "A Test of the Hotelling Valuation Principle." *Journal of Political Economy* 93 (February 1985), 1–25.

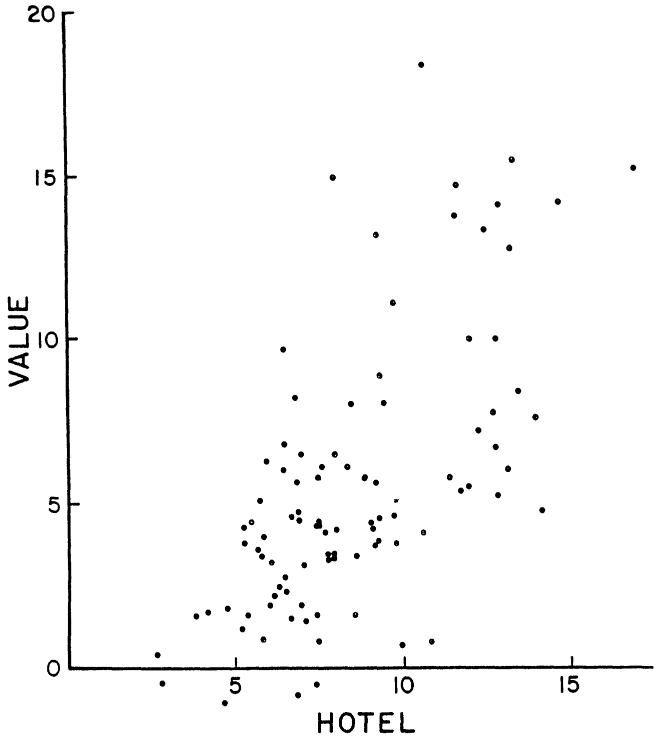

Figure 1. Plot of VALUE versus HOTEL (variables measured in dollars per barrel of reserves)

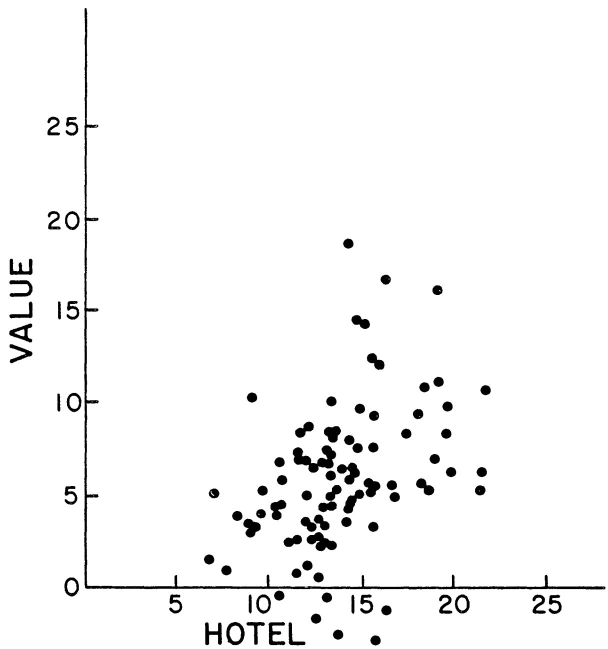

Figure 2. Plot of VALUE versus HOTEL—Oil and Gas Companies (variables measured in dollars per barrel of reserves)

Table II

Basic Regressions—Second Data Set

Regression	Constant	HOTEL	OIL	GAS	OILP	OILC	GASP	GASC	Prices	Costs	R^2	σ_ϵ
(1)	−0.472	0.466									0.148	3.611
	(1.617)	(0.114)										
(2)	−0.720		0.543	0.446							0.153	3.619
	(1.653)		(0.152)	(0.118)								
(3)	−1.893								0.501	−0.363	0.155	3.615
	(2.294)								(0.121)	(0.165)		
(4)	−2.162				0.621	−0.607	0.471	−0.231			0.160	3.642
	(2.509)				(0.198)	(0.359)	(0.136)	(0.268)				

Notes: n = 98. Standard errors are in parentheses.

smaller and is estimated with much less precision; further, the slope coefficient on HOTEL drops from 0.9 to 0.5.

Despite this drop in explanatory power, the results obtained from the decomposition tests (rows 2–4) are still strong. The coefficients on the components of HOTEL are essentially identical (adjusted for the obvious negative signs of the coefficients on the cost terms.) Formal F tests confirm that the restrictions of equal coefficients on these components cannot be rejected at conventional levels of significance.

VI. Why the Differences

The source of these differences can be traced to the different price history of the two sample periods. The first period, which encompassed the Iranian Revolution and the beginning of the Iran-Iraq war, was characterized by relatively sharp movement in oil and gas prices. By constrast, the second sample period is one of relatively quiet oil and gas prices.

Because our data are subject to measurement error, this difference is important. The lower "signal-to-noise" ratio during the second period reduces the precision of our estimates and biases the slope coefficient towards zero.[1]

The extent of the drop in time-series variation in VALUE and HOTEL can be seen by examining the correlation coefficients between VALUE, HOTEL, and time. In the first data set, both variables were highly correlated with time (an R^2 of 0.6 for HOTEL and 0.3 for VALUE); in the second data set, there is virtually no correlation with time (the corresponding R^2's are 0.03 and 0.01).[2]

VII. First Difference Regressions

In our first study, we were concerned that firm-specific effects might lead to autocorrelated individual firm residuals. To guard against mistaken inferences from this source, we reran the basic regression in first difference form with the following result:

$$\begin{aligned} \text{VALUE}_t - \text{VALUE}_{t-1} &= \underset{(0.794)}{0.185} + \underset{(0.226)}{0.978}\,(\text{HOTEL}_t - \text{HOTEL}_{t-1}), \\ R^2 &= 0.262, \quad \sigma = 3.747. \end{aligned}$$

As can be seen, the prediction of "one or a bit less" was robust to taking first differences.

A similar regression can, of course, be run for the second sample. But there is a problem. Because of the lack of temporal variation, the variances of both variables (in first difference form) have dropped substantially. The extent of the

[1] One way of calibrating the loss in precision due to measurement error is to run the "reverse regression" of x on y. It can then be shown (see Leamer [4]) that the ML estimate of the true regression coefficient must lie between the original regression coefficient and the inverse of the coefficient from the reverse regression. In the case of the first sample, this approach would yield a range of (0.910, 2.223). With the second data set, the range more than doubles to (0.466, 3.155).

[2] This is not to say that we are only seeing common trends. In both samples, the coefficient on HOTEL is insensitive to the inclusion of time as a separate variable.

drop is indicated in the following table. What remains is mostly noise, and thus a regression in first difference form can hardly be expected to show any relation between the variables.

	First Data Set	*Second Data Set*	*Ratio*
$VALUE_t - VALUE_{t-1}$	35.70	13.26	2.7
$HOTEL_t - HOTEL_{t-1}$	15.86	4.54	3.5

The first difference regression, for what it is worth, is as follows:

$$VALUE_t - VALUE_{t-1} = \underset{(0.465)}{-0.598} - \underset{(0.220)}{0.264}\,(HOTEL_t - HOTEL_{t-1}),$$
$$R^2 = 0.024, \quad \sigma = 3.627.$$

VIII. Comparative Valuations

The final test we ran in our first study compared the valuations according to the HVP with two publicly available alternative valuations. The first, the "SEC Valuation," is a reporting procedure required by the SEC. Here, the value of oil and gas reserves is estimated as the DPV of cash flows from reserves assuming a continuation of current oil and gas margins, discounted at a mandated rate of ten percent. The second, the "Herold Valuations," published by J. S. Herold, Inc. of Greenwich CT, are well known and widely quoted—although sometimes disparagingly—in the petroleum industry.

We use a test suggested by Davidson and McKinnon [1] to compare the valuations. In the case of our first data set, we can decisively reject either of the alternative valuation techniques.

That is not so here. While we can reject the Herold valuation (and, if we accept it, we cannot reject the HVP), surprisingly we cannot reject the SEC valuation formula, which is little more than an ad hoc accounting formula. Given the arbitrary way in which the SEC valuation is constructed, however, and given the poor initial fits of all three valuation formulas with the second data set, the seeming success of the SEC formula can hardly be called a triumph of accounting over economics.

IX. Royalty Trusts

Although the second sample turned out to be less informative than the first, it did at least contain useful new data on oil and gas Royalty Trusts. These trusts provide a test of the HVP without complications of other assets or potential corporate tax liabilities. The Royalty Trusts, moreover, usually cover "mature" oil and gas fields, where there is less doubt about the amount of recoverable reserves.[3] The advantages of the data on royalty trusts notwithstanding, they must be viewed with caution, for we have only 12 observations.

[3] In the early 1980's, tax considerations led some corporations to distribute their oil and gas properties to shareholders via this mechanism. The earnings from the properties are then paid directly to the owners of the trust, thereby escaping the corporate income tax. The 1984 Tax Reform Act has apparently ended this possibility (see Jacobs and Limberg [3] and footnote 10 of our JPE paper for a discussion of the taxation of Royalty Trusts).

The results, for what they are worth, are consistent with the HVP. As Figure 3 shows, there is a clear relation between market valuation of the reserves (VALUE) and the value according to the HVP (HOTEL). In Table III, the first regression, row 1, gives the results when the data on royalty trusts are pooled with those for oil and gas companies. Although these results are consistent with the "one or a little less" prediction of the HVP, the data fail a test for pooling. The regression in row 2 gives the results for the trusts alone. The coefficient on HOTEL is within a standard error of one, the predicted result. The constant term is also negative, about 1.5 standard deviations from zero. (Given the scatter plot, the observations at either the upper right or lower left of the plot might be viewed as outliers; similar results are obtained when these points are deleted and the regression is rerun.)

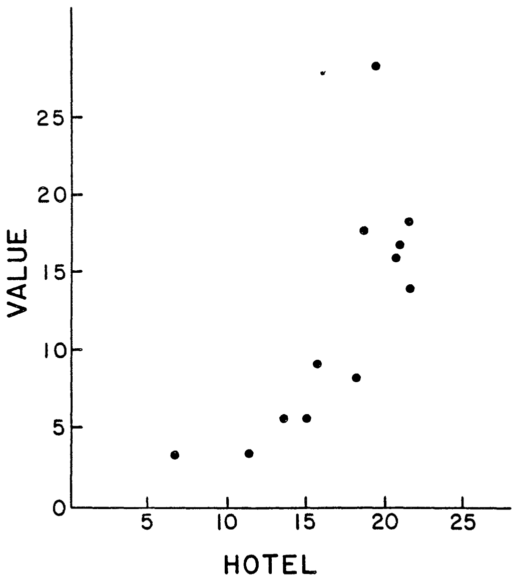

Figure 3. Plot of VALUE versus HOTEL—Royalty Trusts (variables measured in dollars per barrel of reserves)

Table III

Basic Regressions—Second Data Set Using Data on Royalty Trusts

Regression	Constant	HOTEL	OIL	GAS	R^2	σ_ε
(1)	−3.603	0.724			0.283	4.084
	(1.618)	(0.111)				
(2)	−8.839	1.230			0.577	5.147
	(5.873)	(0.333)				
(3)	−8.919		1.117	1.280	0.588	5.364
	(6.125)		(0.427)	(0.364)		

Notes: Dependent variable—market value of oil and gas/barrel equivalent of oil and gas reserves. First regression run on pooled data from oil and gas companies and royalty trusts (n = 110). Second and third regressions run on data from royalty trusts alone (n = 12). Standard errors are in parentheses.

As before, we also broke HOTEL into its two components: OIL and GAS. Since the HVP applies equally well to these components, we would expect the same coefficients on each of the components, and that (row 3) is what we get. (We do not have data to do further separation into prices and costs.)

X. Summary

Our summary can be brief. The follow-up sample proved to be noninformative. Because petroleum prices varied relatively little in 1981–1983, the second sample did not provide as good a basis for testing the HVP as we had hoped. But there are some encouraging signs of more promising experimental conditions to come. The current (December 1984) recriminations about price cutting and quota violations within OPEC suggest its demise might be imminent. If so, we may soon be benefiting both as economists and consumers from dramatic falls in the price of oil.

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DISCUSSION

ALBERT S. KYLE*: We now have two papers by Miller and Upton on the Hotelling Valuation Principle for oil and gas reserves, and the contrast between the results of the first paper and the results of the second appears striking. In the first paper, the HOTEL variable has a coefficient close to its predicited value of "one-or-a-little-less" in both the pooled cross-section regression and in the regression using first differences. In the second paper, the coefficient on the HOTEL variable falls to approximately one-half using the pooled cross-section data, and it is not significantly different from zero using first differences. What went wrong? The authors argue that measurement error is the culprit. Although present in the first sample, it is swamped by large systematic movements in prices. But in the second sample, systematic price movements are so negligible that measurement error biases HOTEL coefficients towards zero in a significant way.

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