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**Price Expectations, Uncertainty,
and Changes in Drilling Activity**

by Ronald H. Schmidt*

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Federal Reserve Bank of Dallas

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Abstract

Estimated models of drilling activity often use stationary lag structures of past prices to capture the effects of price expectations. Results from a model of optimal depletion by members of a competitive fringe, however, suggest replacing the price expectations variable with the difference between expected growth rates in prices and the firm's discount rate to explain changes in drilling activity. Using oil price growth rates for each month estimated with information available at that time, empirical results were found to support the theoretical claim by yielding better goodness-of-fit results than were found with models using lagged price structures.

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1. Introduction

One factor assumed to be an important determinant of drilling activity is the expectation oil and gas producers have about future prices of oil and natural gas at the time that drilling is undertaken. Whether in a cash-flow model for a firm drilling in an individual field, or in a more general optimal depletion model for the entire industry, future prices are a critical ingredient to the decision process. The formation of price expectations, therefore, should be of considerable importance in predicting and explaining movements in the rig count.

The recent introduction of a futures market for crude oil may eventually yield a good proxy for price expectations. Given the lack of historical experience with the crude oil futures market, however, empirical work attempting to incorporate the effect of price expectations often relies on distributed lags of oil and natural gas prices to proxy for expectations formation. Ott and Norman (1983), for example, used the previous year's oil and natural gas prices as proxies for price expectations in an annual model of drilling completions.

Although these models perform well in explaining annual levels of drilling effort, the variables used to proxy the expectations effect have important limitations. Theoretical models of optimal depletion suggest that expectations about growth rates of prices, rather than price levels,

are an important element in the decision process. Hotelling's (1931) rule, which is often cited as an example of an optimal pricing rule, is described in terms of a growth rate in prices. Models of drilling and production decisions, therefore, may benefit from the inclusion of expected growth rates of prices, as well as the actual prices, as explanatory variables.

The purpose of this paper is to identify the explanatory variables suggested by optimal depletion models and to apply the results of the model in an empirical model explaining drilling activity. Although the literature is replete with optimal depletion models, the theoretical model presented below differs in its assumptions about the choice variables and constraints facing domestic oil producers. Especially when dealing with the domestic oil market it is not sufficient to apply the simple version of Hotelling's rule that prices (or marginal revenue in the case of a monopoly) rise at the rate of interest. Hotelling's rule, whether for a competitive firm or a monopolist, is based on the assumption that the price path is determined endogenously by the actions of representative firms: if prices grow at less than the discount rate, all firms attempt to produce in the current period, driving down current prices, but raising the price in the future (because the supply in future periods is diminished). This arbitrage effect results in a price path in which producers are indifferent between production today or production in the future.

When a subset of producers sets the price path for the resource, as is the case today with OPEC, the situation is quite different for a firm

outside of the cartel. In Section II, a model of optimal exploration and development is constructed for a producer in the competitive fringe facing an exogenously determined price -- a price that is not likely to rise at the firm's own discount rate. Results from the theoretical model indicate that not only is the expected growth rate of prices an important explanatory variable for drilling, but the difference between expected increases in the price of oil and the rate of return on alternative investments is important.

The empirical portion of the paper supports the conclusions of the theoretical model. Using a series of expected oil price growth rates estimated in Section III, evidence is presented in Section IV to suggest that this series of estimated oil price growth rates (as well as the mean square errors associated with the estimated rates) has two advantages in the post 1973 era over the usual use of lagged prices in explaining the monthly U.S. rig count. First, from a theoretical standpoint, the model using the constructed series has more desirable long-run equilibrium properties than models formed using lagged oil prices. Second, at least from the perspective of goodness-of-fit tests, the use of the constructed growth rate series has more explanatory power than models incorporating simple lag structures of oil prices. Conclusions from the theoretical and empirical models are then presented in Section V.

II. The Theoretical Model

The role of the growth rate of prices in an optimal depletion model involving both exploration and production has been well established in the literature. Pindyck (1978), for example, compared optimal production and exploration paths for monopolists and competitive producers. Eswaran and Lewis (1984) expanded the Pindyck approach to allow for the full continuum of market structures, from competitive to monopolistic, where solutions were obtained in noncooperative games.

The model developed in this section, however, differs from the previous research by focussing on the production and exploration problem facing a firm in the competitive fringe, given that the price path is exogenously determined. Rather than solving for the optimal price path, the model determines the optimal production and exploration paths as a function of expected prices, a risk premium, and the rate of return to alternative investments (i.e., the firm's discount rate). In many regards, therefore, this problem is more representative of the decision process facing oil producers outside of OPEC: Given that OPEC pegs a price for oil (which can be altered by other than economic factors), how should a firm plan its investment, drilling, and production schedules to maximize the expected present value of profits?

Pindyck's (1978) model provides a useful point of departure for this study. Several differences in the specification, however, alter Pindyck's Euler equations. Most importantly, the Pindyck model determines the price path of the resource endogenously based on revenue maximization behavior by the cartel. This specification, however, has several problems.

Although the recent price cut in 1983 lends evidence to suggest that OPEC does react to some extent to changes in demand and production outside of OPEC, the assumption that prices are determined by OPEC on the basis of a pure profit maximization problem is not supported by price history.

An assumption that would fit more reasonably with oil price history is that oil producers outside of OPEC treat the growth rate of prices as an exogenously determined random variable. U.S. domestic oil producers must base their production and exploration decisions on expectations of oil prices in the future. These expectations are unlikely to be made using game-theory-based oligopolistic optimal depletion models that incorporate feedback responses of the competitive fringe, such as those in Hnyilicza and Pindyck (1976), Salant (1976), Lewis and Schmalensee (1980), and Eswaran and Lewis (1984). Instead, expectations are likely to reflect past changes in oil and gas prices.

The problem facing a typical resource owner outside of the cartel can be described as follows:

$$(1) \quad \max_{w,q} \int_0^{\infty} e^{-\delta t} (P \cdot q - C(R,q) - D(w)) dt$$

$$(2) \quad \text{s.t.} \quad \dot{R} = -q + f(w,Z)$$

$$(3) \quad \dot{Z} = f(w,Z)$$

$$(4) \quad \dot{P} = (r+\epsilon)P$$

$$\text{with } C_R < 0, C_q > 0, C_{Rq} < 0, C_{qq} > 0$$

$$D_w > 0, D_{ww} > 0$$

$$f_w > 0, f_{ww} < 0, f_z < 0$$

where $q(t)$ is resource production by the non-cartel producer,
 $w(t)$ is the exploratory effort (i.e., drilling) for additional reserves,
 $P(t)$ is the price of the resource,
 $R(t)$ are proven reserves at the beginning of the period,
 $Z(t)$ are cumulative discoveries of the resource to date,
 $f(\bullet)$ is the discovery function for new reserves,
 r is the mean expected growth rate of prices,
 δ is the producer's discount rate,
 $C(\bullet)$ is the production cost function,
 $D(\bullet)$ is the exploration cost function, and
 ε is the risk premium associated with future prices of oil (which can be positive or negative depending on the firm's attitude toward risk).^{1/}

The problem for the producer, therefore, is to select a production and drilling schedule to maximize expected profits given an exogenous price path for oil, a production cost function that rises at an increasing rate with production and falls with increases in proven reserves, and an exploration cost function that rises at an increasing rate with drilling effort. Reserves are assumed to rise with discoveries and fall with current production. Discoveries of reserves are positively related to drilling effort -- although there are decreasing returns -- and negatively related to cumulative discoveries. This latter assumption incorporates the depletion effect: as cumulative discoveries rise, the probability and cost of finding new reserves rises, eventually choking off production.

The Hamiltonian for (1)-(4) can be written:

$$(5) \quad H = e^{-\delta t} (P \cdot q - C(R, q) - D(w)) + \lambda_1 (-q + f(w, Z)) + \lambda_2 f(w, Z)$$

First order conditions for a maximum require that:

$$(6) \quad \partial H / \partial q : \lambda_1 = e^{-\delta t} (P - C_q)$$

$$(7) \quad \partial H / \partial w : \lambda_2 = -\lambda_1 + \frac{e^{-\delta t} D_w}{f_w}$$

$$(8) \quad \partial H / \partial R = -e^{-\delta t} C_R = -\lambda_1$$

$$(9) \quad \partial H / \partial Z = f_z (\lambda_1 + \lambda_2) = -\lambda_2$$

Differentiating (6) with respect to time, equating the resulting derivative with the expression in (8), and replacing \dot{R} and \dot{P} with (2) and (4) yields the Euler equation for production:

$$(10) \quad \dot{q} = \frac{(r - \varepsilon - \delta)P + \delta C - C_q (f - q) - C_{qR}}{C_{qq}}$$

As shown in (10), the direction of changes in production over time depends to a large extent on the price level at time t and the difference between the firm's discount rate and the expected growth rate of prices (taking into account risk). If prices are expected to grow at a slower rate than the firm's discount rate, then \dot{q} is likely to be negative: if

the firm expects the discounted value of reserves to decline over time, the firm will seek to deplete rapidly. By contrast, if the price is expected to rise at rates exceeding the firm's discount rate, production is postponed until future periods. As a result, when $(r-\delta-\epsilon)$ is less than (greater than) zero, the optimal production plan calls for high (low) initial production with a decline (increase) over time.

Production over time also depends on the pattern of drilling effort. If discoveries exceed production, q can increase over time. As extraction of a resource first occurs, discoveries typically exceed production, so \dot{q} is likely to be positive. As depletion proceeds, however, the discovery rate falls and costs rise, choking off additional discoveries. The typical pattern of production, therefore, would show a rise in q initially, followed by a decline as the cost of obtaining new reserves rises and production outstrips additions to reserves.

The optimal drilling path can be derived by differentiating (7) with respect to time, setting the resulting derivative equal to (9), and replacing for λ_1 . After rearranging terms, the optimal drilling path can be shown to be:

$$(11) \quad w = \frac{(\delta - f)D + fC}{\frac{D}{w} - \frac{(fD)}{\frac{w}{f}}}$$

The path described by (11) links production and drilling through the effect on production costs. As reserves increase, the cost of production

is assumed to fall. The arguments of the expression on the right hand side of (11) are all positive with the exception of $f_w C_R$. If initial reserves are large (small), C_R is small (large). As a result, \dot{w} is positive (negative). Intuitively, if initial reserves are large, the reduction in production costs afforded by an increase in reserves is small. The initial level of drilling, therefore, is likely to be low. As reserves are depleted, drilling increases to replace those reserves to avoid the increase in production costs, so \dot{w} is positive. Eventually, the depletion of reserves drives down the probability of discovering new reserves, leading to an increase in the cost of finding an additional unit. This cost factor eventually drives down drilling.

The optimal drilling pattern, therefore, depends indirectly on the expected growth rate of prices for the resource. Consider two different growth rates, r_1 and r_2 , where r_1 is greater than r_2 . The optimal production path in the first case either grows faster (if \dot{q} is positive) or decreases at a slower rate (if \dot{q} is negative) relative to the second case. Given the same starting stock of reserves, the initial production level in the r_1 case would be lower than in the r_2 case, given that the cost of postponing production until the future is lower in the r_1 case.

The differential effect on production schedules affects the optimal drilling schedule. Faster reserve depletion leads to more rapid drilling effort. Because production costs are lower initially in the case with the higher price growth rate, initial drilling is lower. If initial reserves are large, \dot{w} is positive in both cases. The faster rate of depletion in the r_1 case leads to a more rapid increase in drilling to replace depleted

reserves. On the other hand, if initial reserves are low, \dot{w} is negative. In that case, the initial level of drilling is higher and the rate of decline is faster in the first case.

A change in price expectations resulting from structural shifts in the resource market (such as an oil price shock), therefore, can be expected to alter the optimal drilling path. If r increases, the rate of change in drilling (after adjusting to the new optimal path) should be slower (assuming that \dot{w} is less than zero). On the other hand, the rate of change in drilling should be higher if price expectations are revised downward. Changes in risk, it should be noted, would have the same impact as an increase in r for firms that are risk averse.

III. Formation of Price Expectations

The theoretical model indicates a potential role for expectations about the future path of prices. Testing the effect of price expectations on drilling activity, of course, requires the construction of a variable for price expectations. In the financial literature, futures markets often provide good proxies for expectations about future price increases. The limited experience with a crude oil futures market, however, precludes such an approach.

Previous attempts to evaluate the effect of price expectations on the production of exhaustible natural resources typically rely on stationary autoregressive processes as proxies for expectations (Feige and Geweke (1979), and Frank and Babunovic (1984)). Ott and Norman (1983) assumed rational expectations formation and argued that the previous period's price contained sufficient information to proxy for expectations.

The series constructed in this study, on the other hand, develops a proxy variable at each point in time that could have been estimated at the time using available price data, without requiring parameters on the expectations variables to be constant over time. Essentially, at each point in time, t , a coefficient for growth rates of prices and the mean square error from the regression were estimated and assigned to observation t . The resulting time series of estimated growth rates and mean square errors were then used in the final regression equation reported in Section IV.^{2/}

The estimated series were obtained from repeated regressions using rolling time horizons. To simplify the problem, the simplest version of Hotelling's rule was selected as the functional form to estimate the growth rates:

$$(12) P(t) = P(0)e^{rt},$$

where r is the growth rate. A set of regressions to estimate r were run using the function:

$$(13) \ln(P(t)) = a + rt + \varepsilon(t), \quad t=1, \dots, s$$

where s is the number of observations on the price variable used to estimate r .^{3/} Estimates of r and the mean square error from the regression were then assigned to observation s . By rolling forward the initial observation by one period and re-estimating, a time series is generated.

The data used in the regressions were seasonally adjusted monthly averages of the domestic refiner's acquisition cost of crude oil in the period 1974-83. Three period lengths, s , were used to estimate the growth

rate and mean square error: 18, 24, and 30 months. The time periods used are selected to preserve degrees of freedom, while still providing sufficient observations to have some confidence in the precision of the estimates. The estimates of $r(s)$ and $MSE(s)$, therefore, have the interpretation of the estimated growth rate of prices in the 18 months, two years, and two and a half years prior to period s , respectively, and the mean square error from those regressions.

Results of the procedure are presented in Charts 1-3 for the three different estimated series. Estimates of r and MSE are plotted against real oil prices (indexed to allow comparison). As shown in the charts, all of the constructed growth rate series exhibit more movement than real oil prices during the 1979-83 period when prices rose rapidly and then fell. The MSE terms increased during the period of rapidly rising prices (resulting from the Iranian revolution) and following the price decline that began in 1981. Comparing across the constructed series, the estimates developed with the shorter time horizons exhibited a faster response to price changes, with a larger average MSE as would be expected.

The relationship between the constructed growth rate series and alternative investments (which is assumed to be a proxy for the firm's discount rate which was available to decisionmakers at time t) is also of considerable interest. The annualized estimated growth rate series for the 30 month case is plotted in Chart 4 against the average yield on corporate bonds. As shown in the chart, the expected growth rate of oil prices was considerably above the return to other investments between the middle of 1979 and April 1982. Not surprisingly, the rig count for the

Chart 1.
THE 18-MONTH CASE. COMPARISON OF THE CONSTRUCTED OIL PRICE GROWTH RATE SERIES
AND MEAN SQUARE ERROR SERIES TO REAL OIL PRICES.
(Indexed by setting the mean of each series for the period 1976-1983 = 100)

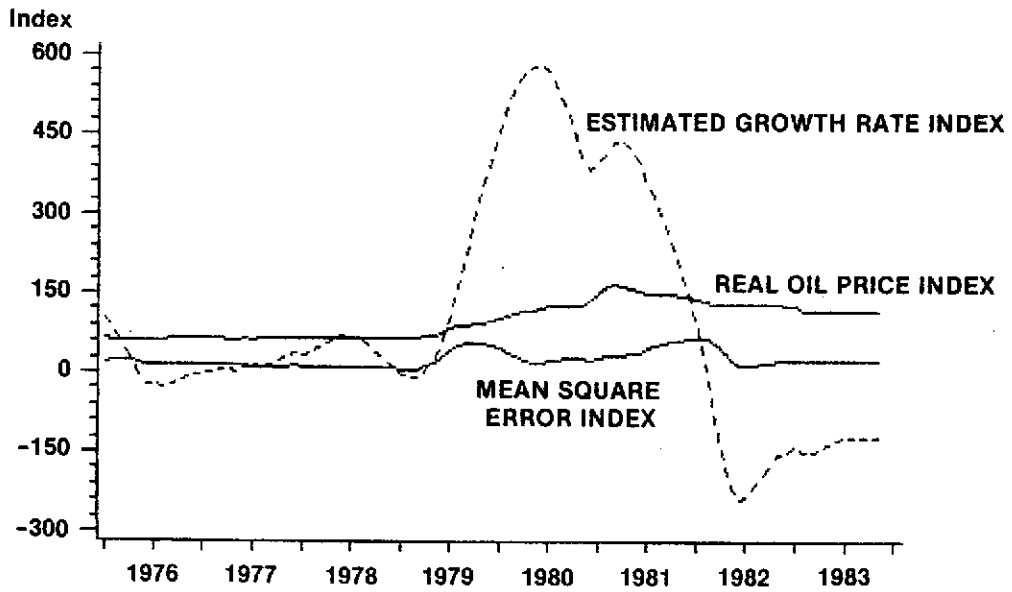


Chart 2.
THE 24-MONTH CASE. COMPARISON OF THE CONSTRUCTED OIL PRICE GROWTH RATE SERIES
AND MEAN SQUARE ERROR SERIES TO REAL OIL PRICES.
(Indexed by setting the mean of each series for the period 1976-1983 = 100)

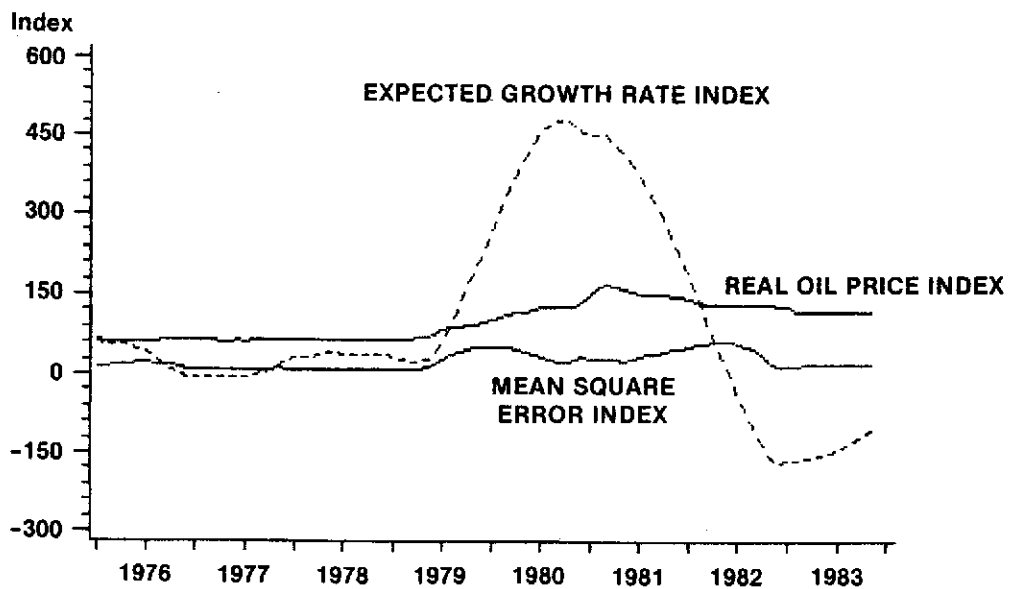


Chart 3.
THE 30-MONTH CASE. COMPARISON OF THE CONSTRUCTED OIL PRICE GROWTH RATE SERIES
AND MEAN SQUARE ERROR SERIES TO REAL OIL PRICES.
(Indexed by setting the mean of each series for the period 1976-1983 = 100)

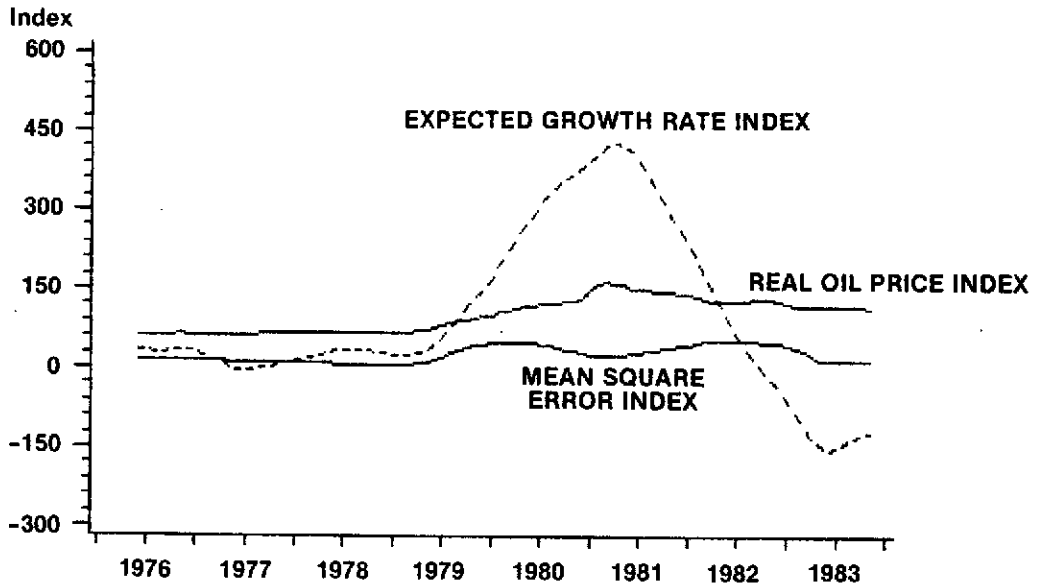
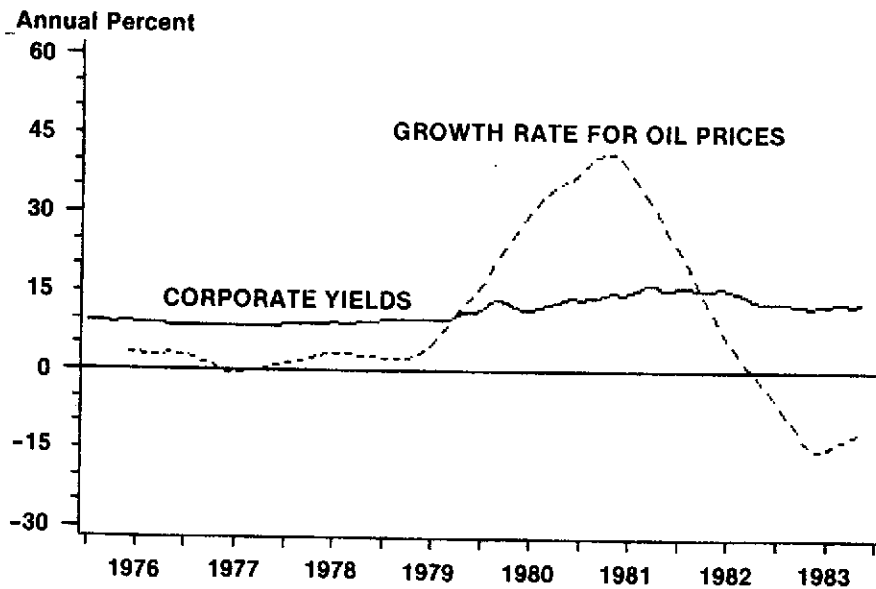


Chart 4.
COMPARISON OF EXPECTED GROWTH RATE IN OIL PRICES
TO AVERAGE YIELD ON CORPORATE BONDS.
(30-Month Case)



U.S. hit an all-time high in December 1981. Given the increase in the MSE variable during the early part of 1982, therefore, movements in the price growth rate adjusted for risk would be expected to correspond closely to movements in the rig count.

IV. Empirical Evidence

The optimal production and exploration paths in equations 10 and 11 hypothesize a relationship between drilling and the growth rate of oil prices relative to alternative investments (δ), adjusted for risk. Given the simplifying assumptions required to keep the optimal depletion problem tractable, other factors likely to be important influences were excluded. The empirical model presented below, therefore, includes other variables that are likely to influence drilling activity.

Following the study by Ott and Norman (1983), drilling was assumed to be a function of drilling costs, the real price of natural gas, the current real price level of oil, as well as the expected growth rate for future oil prices.^{4/} The price expectations variable used by Ott and Norman was replaced with the constructed oil price growth rate variable subtracted from the average yield on corporate bonds. The effects of risk were proxied through the inclusion of the constructed MSE time series. Furthermore, to capture the effects of changes in the business cycle on drilling activity, U.S. industrial production was included.

The estimated model is of the form:

$$(14) \quad \ln(\text{RIG}(t)) = a_0 + a_1 \ln(\text{OIL}(t)) + a_2 \ln(\text{GAS}(t)) + a_3 \ln(\text{IP}(t)) \\ + a_4 R^*(t) + a_5 \text{MSE}(t) + a_6 (\text{COST}(t)) + \varepsilon(t)$$

where RIG is the seasonally adjusted monthly rig count,

OIL is the seasonally adjusted real price of oil,

GAS is the seasonally adjusted real price of natural gas,

IP is the seasonally adjusted level of U.S. industrial production,

R^* is the constructed expectations series, defined by:

$R^*(t) = (r(t) - \delta(t))t$, where $r(t)$ is the estimated series from Section III, and $\delta(t)$ is the average return on corporate bonds,

MSE is the mean square error series from Section III (multiplied by time)^{5/}, and

COST is the seasonally adjusted monthly index of drilling costs.

The form of equation 14 is used to allow straightforward interpretation of the coefficients. Coefficients on variables other than R^* and MSE can be considered elasticities, while the coefficients on R^* and MSE yield the multipliers for changes in expected growth rates and risk premiums on the overall growth in the rig count.

Results of the estimations are presented in Table 1 for the model with and without drilling costs for each of the three proxy series'. As shown in the table, the full model including drilling costs yielded a positive and significant relationship between drilling costs and the rig count for each lag structure used to formulate the expectations series.^{6/} Several problems are known to exist with the drilling cost index used in this study,^{7/} but abstracting from those issues, the more fundamental problem of simultaneity bias is raised. The supply of rigs, it can be argued, is

TABLE 1: Regression Results

| R* | Oil | Gas | Indust. | | | Drill | Adj. | | | |
|---------------------------|-----------------|----------------|----------------|----------------|----------------|----------------|-----------------|----------------|-----------------|-----------------|
| Lag | Const. | Price | Price | Prod. | R* | MSE | Cost | R ² | Rho | Rho2 |
| With drilling costs: | | | | | | | | | | |
| 18 | 5.398 (3.59) | .212 (2.03) | .013 (.13) | .205 (.69) | .109 (5.82) | .027 (2.65) | 2.138 (4.96) | .74 | .74 (10.52) | -- |
| 24 | 5.270 (3.66) | .201 (1.98) | .145 (1.50) | .242 (.85) | .142 (7.27) | .001 (.10) | 1.720 (4.40) | .73 | .78 (11.83) | -- |
| 30 | 4.305 (2.97) | .200 (2.15) | .161 (1.88) | .471 (1.56) | .153 (8.15) | .003 (-.09) | 1.121 (3.44) | .76 | 1.03 (10.07) | -.24 (-2.34) |
| ----- | | | | | | | | | | |
| Excluding drilling costs: | | | | | | | | | | |
| 18 | 5.565 (3.21) | .391 (3.90) | .102 (1.42) | .191 (.55) | .063 (2.60) | .020 (1.65) | | .38 | 1.37 (14.71) | -.46 (-4.95) |
| 24 | 5.696 (3.38) | .383 (3.86) | .129 (1.88) | .164 (.49) | .103 (3.95) | .008 (.73) | | .45 | 1.40 (15.23) | -.49 (-5.39) |
| 30 | 4.154 (2.61) | .298 (3.43) | .149 (1.84) | .516 (1.56) | .137 (5.99) | .008 (.78) | | .61 | 1.16 (11.48) | -.29 (-2.93) |

Notes:

1. All variables except R* and MSE are in logs. The R* and MSE variables are multiplied by time. Coefficients on the logged variables can be interpreted as elasticities, while the coefficients on growth rate term and MSE, when multiplied by those variables (not multiplied by time), represent growth rates.
2. t-statistics are in parenthesis.
3. R* is defined as the difference in the estimated growth rate of oil prices (nominal) from the previous s periods (where s is given in the first column of the table) and the average yield on corporate bonds. MSE is the mean square estimate series from the regressions generating the estimated growth rate series.
4. Rho and Rho2 are first and second autocorrelation parameters, respectively, generated in the autocorrelation correction procedure.

inelastic in the short run, so changes in the demand for rigs are likely to have a positive effect on drilling costs: If demand rises, prices are bid up. This result suggests that a proper treatment of drilling costs requires a simultaneous equations model with both supply and demand equations for drilling rigs. For the purposes of this study, however, this result indicates that a reduced form model excluding drilling costs would be more appropriate.^{8/}

Coefficient estimates for the model excluding drilling costs are presented in the second bank of Table 1. One of the more interesting results involves the relative significance of the constructed R^* variable. Especially in the 24 and 30-month models, this constructed variable has greater significance than oil prices in explaining rig activity.

The effect of the number of observations used to estimate the growth rate can also be seen in changes in the relative significance levels of the R^* and MSE variables. As s increases from 18 to 30 observations, the MSE variable becomes increasingly insignificant, while the R^* variable becomes more significant. This result can be interpreted as either improved precision in estimating R^* (implying a decline in the MSE variable) because of the gain in degrees of freedom in the initial estimation, or that the 30 month model better represents the decision process used by drilling firms.

The coefficient on the MSE variable, however, does not have the expected sign. If firms are risk-averse, the MSE coefficient would be expected to be negative. Instead, the results in Table 1 suggest that drilling firms are more likely to be risk-neutral or risk-takers. Three

explanations can be offered for this result. First, the proxy used for risk -- the mean square error associated with the estimated growth rate of oil prices -- may not be appropriate. Second, it could be argued that drilling firms are more willing to take risks than firms in other industries. Drilling firms, especially wildcatters, are often assumed to be willing to drill in areas where there is significant risk that no oil or gas will be found. Third, the positive relationship between MSE and drilling could be the result of the period used in the estimation. With the exception of the end of the estimation period, the occasions with the largest variance in the estimates of growth rates were associated with periods of sudden price increases.

Natural gas prices are found to have a positive relationship with drilling effort. Although the coefficients are not significantly different from zero at the 95-percent confidence level in a two-tailed test, they are sufficiently significant to reject a one-tail test of the null hypothesis that natural gas prices are negatively related to drilling at the 95-percent confidence level.

Finally, U.S. industrial production had an insignificant effect on drilling in the different models. Given that oil prices were controlled at below market-clearing prices prior to 1981, and that oil imports, rather than domestic oil, are the marginal source of oil, this result is not surprising. Changes in business conditions that affect the demand for oil do not necessarily affect the demand or price of domestic oil to a significant degree.

The advantages of using the estimated growth rate series instead of a model using a lag structure for oil prices are explored in Table 2. In the table, the 30-month model is compared to regressions that use up to three lags of real oil prices instead of the estimated R^* and MSE variables. As shown in the table, the model using the estimated growth rates has a higher adjusted R^2 reported than any of the other models, lending some support for using the growth rate model.

Furthermore, from a dynamic equilibrium standpoint, the growth rate model has a more useful behavioral interpretation. If real oil prices are constant, the value of the constructed variable is negative as long as the real rate of return to other investments is positive. As a result, constant real oil prices should yield a decreasing rig count over time. In particular, the estimates imply that given a real 10-percent annual rate of return on alternative investments and constant real oil prices, the rig count would decline by approximately 1.4-percent per year. By contrast, estimated coefficients on oil prices in the lagged oil price models (which tend to be positive) would not forecast falling rig counts in the case of constant real oil prices. Given that extraction costs are likely to rise over time, a forecast of declining drilling activity in response to constant real oil prices would be more theoretically appealing than a forecast of a constant level of rig activity.

TABLE 2: Comparison with Lagged Price Models

| Regressors | R [*] Case | L=0 | L=1 | L=2 | L=3 |
|---------------------|---------------------|-----------------|------------------|------------------|------------------|
| Intercept | 4.154 (2.61) | 4.431 (2.46) | 3.212 (1.85) | 2.850 (1.67) | 3.024 (1.76) |
| Gas Price | .149 (1.84) | .052 (.69) | -.098 (-1.01) | -.113 (-1.29) | -.123 (-1.27) |
| Indust. Prod. | .516 (1.56) | .357 (.98) | .538 (1.53) | .607 (1.75) | .553 (1.59) |
| R [*] | .137 (5.99) | -- | -- | -- | -- |
| MSE | .008 (0.78) | -- | -- | -- | -- |
| Oil Price | .299 (3.43) | .528 (5.45) | .045 (.21) | .100 (.53) | .015 (.07) |
| Oil Price (t-1) | -- | -- | .217 (3.01) | .244 (1.14) | .289 (1.06) |
| Oil Price (t-2) | -- | -- | -- | .370 (1.98) | .338 (1.25) |
| Oil Price (t-3) | -- | -- | -- | -- | .107 (.52) |
| Adj. R ² | .61 | .33 | .45 | .52 | .46 |
| Rho1 | 1.16 (11.48) | 1.30 (13.43) | .88 (16.58) | 1.13 (11.18) | .87 (16.91) |
| Rho2 | -.29 (-2.93) | -.40 (-4.10) | -- | -.28 (-2.78) | -- |

V. Conclusions

The incorporation of expectations about the growth rate of oil prices relative to alternative investments into models of drilling is appealing from both a theoretical and empirical standpoint. Theoretically, it is reasonable to expect a prospective drilling firm to base their decision to invest in drilling on the expected return to that investment relative to other investments. It was shown that the difference between expected price growth rates and the firm's discount rate is especially important for firms that are part of the competitive fringe facing uncertain future prices. Empirically, the expectations variables created in Section III were shown to have greater significance than oil prices in a model of the monthly U.S. rig count. Furthermore, the model using the constructed expectations variables were shown to have better goodness-of-fit and long-run equilibrium characteristics than models using up to three lags in the real oil price series.

The methodology used to create a series of expected growth rates showed some promise, although there were some difficulties. The approach used in Section III was unable to immediately incorporate major changes in the perception of oil producers resulting from shocks to the market. The recent creation of a crude oil futures market may yield a better proxy for price expectations that incorporate more information about changing perceptions in the market, other than those that can be formed using lagged adjustments to price movements. Furthermore, as data becomes available it should prove interesting to observe if the expectations formation process as measured here is altered as producers synthesize information from the futures market into their current drilling decisions.

Footnotes

1. The differences with the Pindyck model are rapidly apparent. First, the price path is given explicitly as a constraint. Second, the production cost function (which was an average cost function in the Pindyck model) is a total cost function.
2. This separate formulation of an expected price series allows the final estimates reported in Section IV to be used in a linear model. A similar result could be obtained by incorporating the expectation function directly into the final equations and using nonlinear estimation. The only difference between the two methods is the assumed error structure underlying the model. It is assumed in this study that it is appropriate to use the estimated r and MSE variables in the final regression equation and assume that the error term in the final regression is normally distributed with mean zero. The explicit behavioral assumption is that a drilling firm uses the expected growth rate and standard error information in making their decisions at time t .
3. Alternative price expectations models formed with ARIMA processes are not possible given the abrupt shifts in oil prices experienced during this period.
4. Oil (refiner's domestic acquisition cost) and natural gas prices (the producer price index for natural gas) were deflated by the consumer price index to get "real" prices. Because the growth rate series was obtained from estimations using nominal rather than real oil prices, the growth rate series used in the regressions in Table 1 can be interpreted as "real" growth rates as long as the inflationary expectations component in the growth rate series is the same as that embedded in the average yield on corporate bonds: the series used in the regressions is the difference in the two annual rates.
5. Both R^* and MSE were multiplied by time. As a result, the coefficient estimates have a special meaning. The coefficients can be interpreted as the multiplier effect on the overall growth rate of the rig count resulting from a revision in perceptions about the mean and variance of the path of future oil prices.
6. For each of the regressions reported in Tables 1 and 2 the time period was kept the same. The 30-month model, therefore, has the same number of degrees of freedom as the 18-month model.
7. One of the major problems with the BLS drilling cost series (producer price index for oil and gas extraction equipment) is that it relies on list prices for equipment. In periods with slack demand, list prices tend to remain fixed with producers offering large discounts. As a

result, the series tends to understate the decline in drilling costs during a downturn in rig activity.

8. Ott and Norman found a negative relationship between drilling costs and the number of well completions based on annual data. Results from this estimation indicate that the time interval used in the analysis is clearly important in establishing the relationship.

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