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1 **The Effect of Price Expectations on Drilling Activity**
Ronald H. Schmidt

Empirical analysis supports the theoretical proposition that price expectations are an important determinant of drilling for oil and natural gas. In particular, the difference between the expected growth rate of oil prices and the average return on alternative investments directly affects drilling activity over time. Adjustments in expectations about the growth rate of future oil prices—formed on the basis of past price movements—are shown to explain both the recent rebound and the longer-term secular decline in the monthly U.S. rig count.

13 **Racial Earnings Differentials in Texas**
Alberto E. Davila

Racial wage differentials are high in Texas relative to the nation, but the sources of these differentials are about the same in the two areas. Non-Hispanic white males have, on average, more education and a higher level of English proficiency than Hispanic males, and these differences explain nearly all of the earnings differential between Hispanics and whites. On the other hand, differences in education explain only a fourth of the black-white earnings gap. These findings suggest that more schooling for racial minorities would help narrow the differences in earnings, particularly for Hispanics. Affirmative action may be helpful for blacks, but more research on the sources of the black-white earnings differential is needed.

25 **Articles in 1984**

The Effect of Price Expectations on Drilling Activity

*By Ronald H. Schmidt**

Drilling activity, as measured by the number of rotary rigs running, is often associated with the health of the energy sector of the economy. When the rig count rises, suppliers of oil and gas extraction equipment, steel, cement, drilling mud, and other oil field products experience growth. Especially in energy-producing states, movements in the rig count are important indicators of economic activity.

Factors influencing the rig count, therefore, are of considerable interest. Costs of drilling, the probability of striking oil or natural gas, and the prevailing prices of oil and natural gas are all likely to affect a firm's interest in drilling.

Because oil and natural gas are produced from wells over a long period, however, the decision to drill also depends on expectations about the future path of prices. The profitability of drilling an oil or gas well depends on the expected stream of revenues attributed to the venture. Revised expectations about prices, which can result from political events or shifts in energy demand, change the profitability of a well by increasing or decreasing the expected stream of revenues from that well.

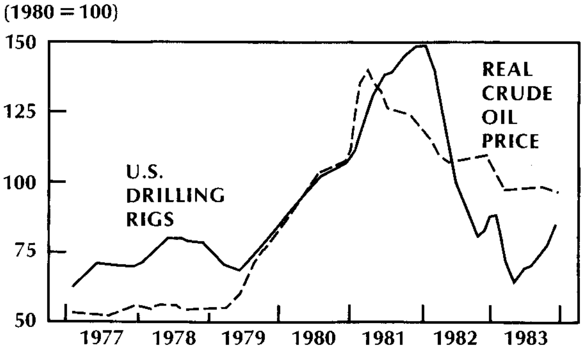
Price expectations can go a long way in explaining the recent behavior of the rig count. In Chart 1 the rig count is shown to have responded substantially to changes in oil prices, although with a lag. This lagged response is particularly noticeable since the middle of 1980. In fact, the rig count rose to its highest level in December 1981, even though inflation-adjusted oil prices had been falling for eight months. The rig count then plunged over 40 percent in 1982, a year in which nominal prices remained constant.

This relationship between the price of oil and the rig count suggests that price expectations are formed using recent historical experience. The lagged response of the rig count to changes in prices, however, seems to imply that these expectations change relatively slowly, not instantaneously. The rapid increase in the rig count in 1981, despite falling oil prices through most of the year, can be explained by expectations held at the time that

* *Ronald H. Schmidt is an economist at the Federal Reserve Bank of Dallas. The views expressed are those of the author and do not necessarily reflect the positions of the Federal Reserve Bank of Dallas or the Federal Reserve System.*

Chart 1

Indexes of Rig Count and Real Oil Price



SOURCES OF PRIMARY DATA: Hughes Tool Company. U.S. Bureau of Labor Statistics. U.S. Department of Energy.

prices could rise to $50 per barrel in the next few years. Similarly, the 1982 collapse of the rig count can be explained by a reduction in the expected rate of oil price growth—even negative growth of prices.

Empirical estimates support the role of price expectations formed through historical experience in explaining the magnitude of the U.S. rig count. Furthermore, the estimates indicate that as long as nominal crude oil prices remain at the official price of $29 per barrel for Saudi light, a slight but steady decline in the average level of the rig count can be expected.

Theoretical background

The relationship between the growth rate of prices for a resource, such as oil or natural gas, and drilling for and producing the resource can be understood in the context of a dynamic optimization model. The decisions are inherently intertemporal in nature, with producers choosing the most profitable way to discover, develop, and market a resource over time.

The relationship between the optimal production of a nonrenewable resource such as oil or natural gas and the rate of increase in its price was derived by Hotelling in 1931.[1] "Hotelling's rule," characterizing the relationship for a competitive firm, suggests that the price of an exhaustible resource, net of extraction costs, would grow at the rate of interest. Intuitively, a producer would only hold the resource in the ground for future production if its value was appreciating faster than the proceeds from current sales of the resource would appreciate if invested in other assets.

Considerable research has been undertaken to extend the theoretical model and to examine whether Hotelling's rule has been followed empirically.[2] One of these extensions, the decision to explore for new reserves, is especially important in the optimization problem because it allows the initial reserve stock to be increased over time. With exploration included, a firm must decide the best way to develop and produce new reserves as well as to exploit reserves already discovered.

The mechanism by which proven reserves of the resource can be augmented over time is assumed, in the case of oil, to be drilling. This approach assumes that drilling is for the purpose of adding to reserves and does not differentiate between development and exploratory drilling.[3]

In addition to incorporating exploration, Hotelling's simple optimal depletion framework must be modified to model the problem facing an oil or gas extraction firm in the United States. A domestic oil firm can be considered a price taker in the current market, where the price is assumed to be set by the Organization of Petroleum Exporting Countries (OPEC). Although the level of output by U.S. producers may have some eventual feedback effect on

1. Harold Hotelling, "The Economics of Exhaustible Resources," *Journal of Political Economy* 39 (April 1931): 137–75.

2. Examples of more advanced theoretical models can be found in Robert S. Pindyck, "The Optimal Exploration and Production of Nonrenewable Resources," *Journal of Political Economy* 86 (October 1978): 841–61; and Mukesh Eswaran and Tracy R. Lewis, "Ultimate Recovery of an Exhaustible Resource Under Different Market Structures," *Journal of Environmental Economics and Management* 11 (March 1984): 55–69. An example of empirical tests is presented in Edgar Feige and John Geweke, "Testing the Empirical Implications of Hotelling's Principle," SSRI Workshop Series, no. 7924 (University of Wisconsin-Madison, Social Systems Research Institute, September 1979).

3. Development drilling, as well as exploratory drilling, can be thought of as expanding reserves. Additional development drilling increases the quantity of oil or natural gas that can be recovered from a reservoir.

the official price established by OPEC, the degree of market power exercised by individual firms is minimal. As a result, the problem for a domestic firm can be cast in the framework of a producer facing an exogenously determined price path for the resource.

The primary difference between this approach and one employed elsewhere is that the growth rate of prices (net of extraction costs) may differ from the firm's discount rate. This result contrasts with Hotelling's rule, which is based on the assumption that all firms are competitive price takers. The market structure posed in the model here, on the other hand, assumes the existence of a price-setting dominant firm.[4] The growth rate of prices set by the dominant firm (OPEC) is also assumed to change over time in response to exogenous and unpredictable shocks.

The problem addressed by the theoretical model, therefore, is the following: given that OPEC pegs an oil price, which might change for other than economic reasons, what factors should a firm consider when planning its drilling and production schedules to maximize the expected present value of profits?

Factors influencing drilling and production

As shown in Appendix A, changes in the optimal levels of production and drilling over time depend to a large extent on the difference between the expected growth rate of prices and the firm's discount rate. If prices are expected to grow at a slower rate than the firm's discount rate, production is likely to fall over time because the discounted value of a unit of production declines. Consequently, the firm will seek to deplete the reserves rapidly. In contrast, if the price is expected to rise at rates exceeding the firm's discount rate, production is postponed until future periods.

4. This approach differs considerably from that used by other models. Generally, optimal depletion models solve for optimal price paths and assume that production supports those paths. In contrast, this model determines the optimal quantity over time, assuming that the price path is given as a constraint. As shown in Appendix A, production occurs in more than one period despite the fact that the discounted price falls over time. This condition exists because the cost of production is assumed to rise at an increasing rate with rising production and falling reserves.

The decision to drill is related to the decision to produce (see the box). Because producing the resource is assumed to be increasingly costly when reserves fall, drilling acts to restrain production cost increases. Production is influenced by drilling, therefore, because drilling is assumed to expand the level of proven reserves of the resource. If production is to increase, drilling must first take place to expand reserves. If discoveries exceed production, then reserves rise, making an increase in production feasible.

When a resource is first extracted, discoveries typically exceed production, so reserves and production increase. As depletion proceeds, however, the discovery rate falls and costs rise, choking off additional discoveries and leading to declining reserves and production.

Chart 2 demonstrates this relationship between oil reserves and production in Texas. Reserves grew initially as additions to reserves from new drilling exceeded production. Over time, however, production rose and additions to reserves were unable to keep up. Finally, reserves began to fall, driving down production.

Effects of revised price expectations

A revision in expectations about the growth rate of future prices can shift the drilling and production schedules. An increase in the rate of growth of prices raises the value of a barrel's production in the future relative to the value of that barrel under the original expectations. An upward revision in the expected average growth rate of prices, therefore, would be expected to spread out the drilling and production profiles over a longer period. A downward revision in the expected growth of prices would have the opposite effect because of the resulting reduction in the relative return to holding off production for future periods.

To illustrate, consider the effect of a downward shift in a producer's price expectations, such as may have occurred following the decline in real oil prices in 1982. In this case, because production in the future is expected to receive lower prices than originally thought with the higher expectations held previously, producers would have an incentive to move some production forward in time. Some of the advantages of putting off and reducing costs of production in the future would be eliminated because the value of the oil produced in the future would be

The Relationship Between Drilling and Production

Drilling and production in the model presented here interact through the effect of changes in reserves on the cost of producing the resource. By increasing the quantity of reserves, drilling is assumed to have the effect of lowering costs of producing the resource, thereby affecting the profitability of production.

To illustrate this relationship, consider a hypothetical oil producer. If all reserves of oil are discovered and ready for production—making further drilling unnecessary—the producer will choose a path of production for the known reserve so as to maximize expected profits. The producer will take into account the expected growth of the price of the resource and the expected cost of production. Because costs are assumed to rise with production within a period (it becomes increasingly costly to produce as existing pumping facilities approach capacity), the producer will seek to spread out the production over time to achieve the best trade-off between sales in future periods and lower costs of production in the present.

Now assume that proven reserves can be augmented by drilling. By choosing to drill, a producer is accepting current costs of adding to reserves in return for a reduction in the cost of producing in future periods. The producer, therefore, will choose to drill only wells that reduce the expected value of future production costs by more than the cost of drilling the wells in the present.

Expected reductions in future costs depend, of course, on how far into the future those reductions occur. The value is higher if the gains are expected soon. Drilling, therefore, would be expected close to the period in which the gains would be realized. A producer that expects costs of production to begin rising in a future period will drill in anticipation of that future level of production.

Drilling and production, then, are related through the effect that additional reserves from drilling have on production costs. As reserves are driven down by production, costs of production rise. As costs of production rise, the producer finds it worthwhile to augment existing reserves by drilling so as to keep costs of production from rising rapidly.

decreased by the lower price received for that oil.

With the production plan moved forward in time, the drilling schedule must also be moved forward to ensure that reserves are available to minimize costs of production. After the initial readjustment to a new "optimal" path, the drilling path would be accelerated compared with the previous "optimal" path: increasing faster to augment reserves if initial reserves are low, falling faster as cumulative discoveries rise and reduce the probability of finding new oil.

A proxy for expected growth of oil prices

To test the proposition that drilling responds to changes in expectations about the growth of oil prices, it is necessary to construct a measure of these expectations.[5] Expectations are often proxied in econometric models by prices reported in futures markets, which are claimed to give a reasonable approximation of the prices the industry expects to prevail in the future. Unfortunately, a crude oil futures market only recently opened, so futures prices are not available.

Most models have included the lagged oil price level as an explanatory variable to proxy for the expectations effect. The use of such a proxy, however, has two problems. First, although lagged prices perform well as variables when oil prices are stable over time, they are not well suited for modeling major shifts in the oil market. Second, the economic theory discussed above indicates that expectations about the *growth rate* of prices should be used.[6]

One difficulty in creating a series of price expectations or expected growth rates to address these

5. Expectations about natural gas prices were not included. Because of federal price regulations, natural gas prices rose at a nearly constant rate for most of the period studied, making changes in expectations relatively infrequent.

6. Not only is the estimated growth rate series model preferable to a lagged variable model on theoretical grounds; empirical tests also found the growth rate model had more explanatory power than models using lagged oil prices. See Ronald H. Schmidt, "Price Expectations, Uncertainty, and Changes in Drilling Activity," Federal Reserve Bank of Dallas Research Paper no. 8405 (Dallas, July 1984). A more complete description of the methodology used to construct the expectations variables is also presented in that paper.

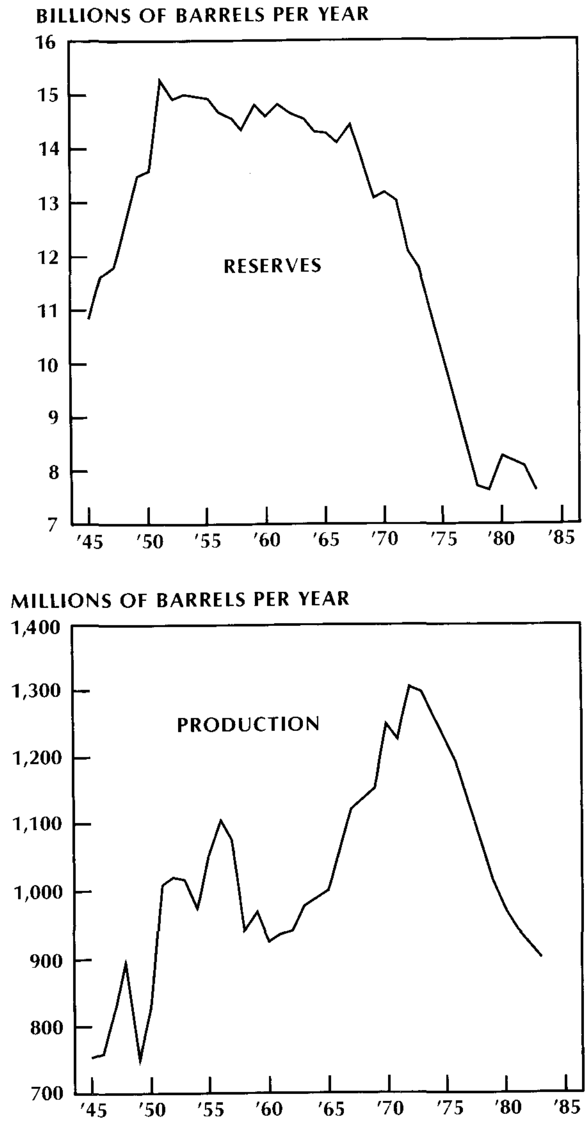
two problems is modeling how producers might have formed those expectations at each point in the past. In retrospect, it is tempting to include explanatory variables that would shed light on major changes that were about to occur in the oil market, such as the oil embargo, the outbreak of war between Iran and Iraq, and major changes in federal regulations. In all these cases, the fundamental difficulty with building a sophisticated model of expectations is determining when and how such information would have been incorporated into a producer's expectations.

Alternatively, a set of simple expectations series can be constructed to avoid this problem of retrospective modeling. As described in Appendix B, three simple growth rate series were constructed based on historical data available at the time drilling occurred. The series are the average growth rates of oil prices—refiner acquisition costs of domestic crude oil—during the 18, 24, and 30 months preceding each period. (Only one price growth rate series is used at a time in the drilling models reported below.)

Furthermore, to capture the effect of changing uncertainty about the estimates, the series of mean square errors of the estimated growth rates were constructed. It is hypothesized that as the mean square error (*MSE*) rises—often caused by a major shift in the price path—drilling will also be affected.

Although these growth rate and *MSE* series have the advantage of having been available at the time and are likely to have been at least proxies for important factors in the decision process, their simple structure ignores some issues that should be kept in mind when interpreting the results. Most significant, the price series is not adjusted for changes in state taxes or federal regulations—including the windfall profit tax (WPT). The WPT, enacted in 1978, has had the effect of driving a wedge between the price received by producers and the price paid by refiners, so the price paid by refiners overstates the after-tax price received by producers.[7]

Chart 2
Crude Oil Reserves and Production in Texas



SOURCES OF PRIMARY DATA: American Gas Association.
U.S. Department of Energy.

7. In fact, because the WPT is based on the difference between a base price that rises at a legislated rate and the actual price, the after-tax price to a producer can rise at the same time the pretax price falls. The price series without a correction for WPT, therefore, is likely to be more volatile than the after-tax series faced by producers.

Unfortunately, an adjustment to the price series is not easily achievable. The effect of the WPT is not uniform across new drilling activity. Instead, the tax rate depends on the official pre-WPT classification of the reservoir into which the well is drilled. This problem makes it virtually impossible to calculate an expected growth rate of oil prices net of taxes that would be appropriate for all drilling decisions.

The price growth rate series were further modified before being included in a monthly model of the U.S. rig count. In the theoretical model, it was shown that the difference between the growth rate and the firm's discount rate was an explanatory variable. To form this net return variable, each estimated annualized growth rate series was subtracted from the average yield on corporate bonds for that month to form a variable defined as R^*.

Along with R^*, the *MSE* variable was included so as to examine the separate effect that changes in the variance of the estimated growth rate had on drilling decisions. Consequently, the pair of variables R^* and *MSE* for each of the three models can be interpreted as the expected growth of oil prices relative to the alternative yield on corporate bonds and the error associated with that estimate.

Empirical results

To test the proposition that changes in the expected growth of oil prices (relative to the return on other investments) affect drilling, a monthly model of the U.S. rig count was constructed and estimated for the period 1976–83.[8] The rig count was assumed to be a function of the real price of natural gas and the current real price level of oil, as well as the proxy price expectations variable.[9] Furthermore, because business cycles may influence the rig count through changes in energy consumption or in energy investment, U.S. industrial production was included as a variable.

The estimated model is of the form

$$\begin{aligned} \ln(RIG_t) = {} & a_0 + a_1\ln(OIL_t) \\ & + a_2\ln(GAS_t) + a_3\ln(IP_t) \\ & + a_4R_t^* + a_5MSE_t + \varepsilon_t, \end{aligned}$$

where *RIG* is the monthly rig count, *OIL* is the concurrent real price of oil, *GAS* is the concurrent real price of natural gas, *IP* is the level of U.S. industrial production, and R^* and *MSE* refer to the estimated expected net growth of oil prices and the mean square error series.[10] To eliminate cyclical fluctuations attributable to seasonal factors, *RIG*, *OIL*, *GAS*, and *IP* were all seasonally adjusted.

The log-linear form of the equation allows straightforward interpretation of the coefficients. Both the R^* and *MSE* variables were multiplied by a trend term before the estimation. By doing so, the estimated coefficients can be interpreted as growth rate multipliers: the coefficient gives the effect of a change in the expected growth rate of oil prices (relative to the return on corporate bonds) on the growth of the rig count over time. If the coefficient is positive, therefore, the rig count will rise over time as long as oil prices are expected to grow faster than the return on other investments. Coefficients on variables other than R^* and *MSE* can be interpreted as elasticities.

8. The regression used monthly data from July 1976 to November 1983. Estimates of the growth rate variables used price data beginning with January 1974.

9. Oil prices (refiner 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.

10. Drilling costs are not included in the models specified here. Estimations including drilling costs yielded a positive and significant relationship between drilling costs and the rig count for each of the three models. Several problems are known to exist with the drilling cost index used in the model (in particular, the drilling cost series of the U.S. Bureau of Labor Statistics uses list prices for equipment, which do not reflect the discounting occurring when demand falls), but even aside from those issues, the more fundamental problem of simultaneity bias is raised. The supply of rigs, it can be argued, is 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. Preliminary tests for Granger causality supported the hypothesis that changes in the rig count tend to cause changes in drilling costs, rather than vice versa. This result suggests that in the absence of a simultaneous equation model, a reduced-form model excluding drilling costs is appropriate for the purpose of this study.

Table 1
REGRESSION RESULTS FOR DRILLING ACTIVITY DETERMINANTS
(Dependent variable = seasonally adjusted monthly U.S. rig count)

R^* lag	Constant	Oil price	Gas price	Industrial production	R^*	*MSE*	$\bar{R}^2$	Rho_1	Rho_2
18 months . . .	5.565	.391	.102	.191	.063	.020	.38	1.37	−.46
	(3.21)	(3.90)	(1.42)	(.55)	(2.60)	(1.65)		(14.71)	(−4.95)
24 months . . .	5.696	.383	.129	.164	.103	.008	.45	1.40	−.49
	(3.38)	(3.86)	(1.88)	(.49)	(3.95)	(.73)		(15.23)	(−5.39)
30 months . . .	4.154	.298	.149	.516	.137	.008	.61	1.16	−.29
	(2.61)	(3.43)	(1.84)	(1.56)	(5.99)	(.78)		(11.48)	(−2.93)

NOTE: See the text for definitions of the variables.

All variables except R^* and *MSE* are in logarithms. The R^* and *MSE* variables are multiplied by time. Coefficients on the logged variables can be interpreted as elasticities; the coefficients on the growth rate term and *MSE*, when multiplied by those variables (not multiplied by time), represent growth rates.

The reported $\bar{R}^2$ is based on the explanatory power of the independent variables in the *transformed equation*—after autocorrelation has been removed.

Rho_1 and rho_2 are the first and second autocorrelation parameters, generated in the autocorrelation correction procedure.

Figures in parentheses are *t* statistics.

The equation was estimated for three different models, with each model using an R^* and *MSE* series formed from the 18, 24, or 30 months preceding the observation. Results of the estimations are presented in Table 1. One of the more interesting results involves the significance of the constructed R^* variable relative to concurrent real oil prices. Especially in the 24- and 30-month models, this constructed variable has greater significance than oil prices in explaining rig activity. Oil prices also have the expected sign, indicating a positive and significant relationship between changes in oil prices and the rig count.

Natural gas prices are also found to have a positive, although weaker, relationship with drilling effort. The coefficients on natural gas prices are significantly greater than or equal to zero at the 95-percent confidence level in a one-tailed test, but the coefficients are not significantly different from zero at the 95-percent confidence level in a two-tailed test.

The coefficients on the *MSE* variables do not have the expected sign, but the coefficients are not significantly different from zero.[11] It is interesting to note that as the number of months used to estimate the R^* and *MSE* variables rises from 18 to 30, the *MSE* variable drops in significance while the R^* variable becomes increasingly significant. This result can be interpreted either as improved precision in estimating R^* (implying a decline in the *MSE* variable) because of the gain in degrees of freedom in the initial estimation forming the R^* variable or as an indication that the 30-month model better represents the decision process used by drilling firms.

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 before 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 total demand for oil do not necessarily have a significant effect on the demand for or price of domestic oil.

11. One explanation for the positive and insignificant sign on the *MSE* variables is that with the exception of the end of the period, occasions of high *MSE* coincide with major price *increases*. Because there has been only limited experience with price decreases, it is not surprising to observe a positive relationship between drilling and *MSE* during the period studied.

From a long-run dynamic equilibrium standpoint, the results in the table have a useful behavioral interpretation. The value of R^*, which is the difference between the growth rate of oil prices and the average return on alternative investments, is negative as long as the real rates of return on those other investments are positive. As a result, constant real oil prices should yield a decreasing rig count over time because investments in nondrilling ventures are relatively more attractive. In particular, the estimates from the 30-month model imply that given constant real oil prices and a real annual rate of return of 10 percent on alternative investments, the rig count would decline approximately 1.4 percent per year.

Furthermore, the results in the table provide an explanation for the recent behavior of the rig count. After the oil price cut in March 1983, the rig count rose. The rig count in the first 10 months of 1984 was 11 percent higher than in the same period in 1983, despite a continued decline in real oil prices. This occurrence may be partially explained by a revision in price expectations. Assuming that expectations about the growth of prices are built using past price behavior, the expectations in the period after the price cut reflected this strong negative growth (as can be seen in Chart D in Appendix B). As prices stabilized, the expected negative growth rate diminished in absolute value, and the predicted rig count rose in the short run. As long as oil prices fail to rise, however, long-run downward pressure on the rig count can be expected.

Conclusions

Because drilling depends to a large extent on movements in crude oil and natural gas prices, the outlook for drilling in 1985 is not especially bright. Continued downward pressure on oil prices, caused by the glut in the world oil market, is expected to keep nominal prices from rising in 1985. Furthermore, although approximately 60 percent of natural gas is scheduled for price deregulation in January 1985, the surplus conditions in the natural gas market have decreased prospects for significantly higher natural gas prices.

The implications of these expected constant or falling real prices for oil and gas are for small reductions in the average rig count in 1985. A decline in real oil prices can be blamed directly for part of the expected decrease. The results in the table, however, further suggest that steady or falling oil prices can decrease the rig count through the expectations factor. As long as producers expect the increase in prices to be less than the rate of return on other investments, there will be less drilling activity.

This prediction of a decline in average drilling activity from 1984 to 1985 must, of course, be hedged by other factors. Most important, the oil market has been characterized by unexpected shocks since 1973. As a result, expectations about oil prices could be affected drastically by changes in the Middle East political situation. Furthermore, the model in the table does not account for changes in government policy toward lease sales or drilling that would alter the incentives for drilling new wells.

Finally, the effect of natural gas deregulation must be considered. It is too early to predict the extent to which drilling for natural gas will be affected by the change from a regulated to a largely deregulated environment. The elimination of price controls on new gas could lead to increased drilling as producers compete in commonly held fields or could lead to a decrease if price expectations for natural gas are revised downward because of continuation of the current natural gas glut.

Appendix A

The Theoretical Model

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

$$\text{(A.1)}\quad \underset{q,w}{\text{Max}}\ W = \int_0^{\infty} e^{-\delta t}[P \cdot q - C(R,q) - D(w)]dt$$

subject to

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

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

$$\text{(A.4)}\quad \dot{P} = (r + \varepsilon)P$$

with

$C_R < 0,\ C_q > 0,\ C_{qR} < 0,\ C_{qq} > 0,\ C_{RR} > 0$

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

$f_w > 0,\ f_{ww} < 0,\ f_Z < 0,\ f_{wZ} < 0,$[1]

where

q = resource production by the noncartel producer
w = exploratory effort (that is, drilling) for additional reserves
δ = producer's discount rate
P = price of the resource
$C(R,q)$ = production cost function
$D(w)$ = exploration cost function
R = proven reserves at the beginning of the period
$f(w,Z)$ = discovery function for new reserves
Z = cumulative discoveries of the resource to date
r = mean expected growth rate of prices
ε = risk premium associated with future prices of oil (which can be positive or negative, depending on the firm's attitude toward risk).

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 with falling proven reserves, and an exploration cost function that rises at an increasing rate with drilling effort.[2] 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 increase, the probability and cost of finding new reserves rise, eventually choking off production.

The Hamiltonian for (A.1) through (A.4) can be written

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

First-order conditions for a maximum require that

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

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

$$\text{(A.8)}\quad \partial H/\partial R = -e^{-\delta t}C_R = -\dot{\lambda}_1$$

$$\text{(A.9)}\quad \partial H/\partial Z = f_Z(\lambda_1 + \lambda_2) = -\dot{\lambda}_2.$$

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

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

As shown in (A.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 expected growth rate of prices and the firm's discount rate (taking into account risk). Production over time also depends on the pattern of drilling effort. If discoveries exceed production, q can increase over time.

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

1. For notational convenience, a dot above a variable signifies the derivative of that variable with respect to time—that is, the instantaneous rate of change in the variable. Similarly, a variable subscript indicates the partial derivative of that variable with respect to the subscript argument. Where applicable, a second subscript refers to the second, or cross, partial derivative of the variable with respect to the subscript arguments. Time subscripts have been suppressed.

2. There are two major differences between this model and the model in Robert S. Pindyck, "The Optimal Exploration and Production of Nonrenewable Resources," *Journal of Political Economy* 86 (October 1978): 841-61. 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.

rearranging terms, the optimal drilling path can be shown to be

$$\text{(A.11)} \qquad \dot{w} = \frac{\left(\delta - f_Z - \dfrac{f_{wZ}f}{f_w}\right)D_w + f_w C_R}{D_{ww} - \dfrac{f_{ww}D_w}{f_w}}.$$

The path described by (A.11) links drilling to production through the effect of reserves 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 (A.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).

Appendix B

Forming an Expected Price Growth Rate Series

Testing the effect of price expectations on drilling activity requires the construction of a variable for price expectations. The limited experience with a crude oil futures market, however, precludes using futures prices as the expectations variable, necessitating an alternative 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.[1] Other researchers have assumed rational expectations formation and argued that the previous period's price contained sufficient information to proxy for expectations.[2]

The series constructed in this study, on the other hand, develops a proxy variable for each point in time that could have been estimated at the time by using available price data, without requiring parameters on the expectations variables to be constant over time. For 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 equations reported in Table 1.[3]

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:

$$\text{(B.1)} \qquad P_t = P_0 e^{rt},$$

where r is the growth rate. A set of regressions to

1. See, for example, Edgar Feige and John Geweke, "Testing the Empirical Implications of Hotelling's Principle," SSRI Workshop Series, no. 7924 (University of Wisconsin-Madison, Social Systems Research Institute, September 1979); and Jeff Frank and Mark Babunovic, "An Investment Model of Natural Resource Markets," *Economica* 51 (February 1984): 83–95.

2. For an example of this research, see Deborah A. Ott and Donald A. Norman, "An Empirical Analysis of the Determinants of Petroleum Drilling," American Petroleum Institute Research Study no. 032 (Washington, D.C., December 1983).

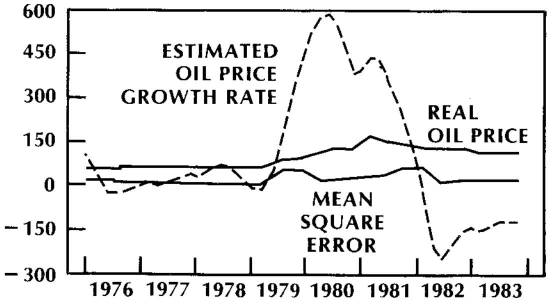
3. This separate formulation of an expected price series allows the final estimates reported in the table to be used in a linear model. A similar result could be obtained by building the expectations function directly into the final equations and using nonlinear estimation. The only difference between the two methods is the assumed error structure underlying the model. In this study, it is assumed that the error term in the final regression equation incorporating the estimated r and MSE variables 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 its decisions at time t.

4. Alternative price expectations models formed with ARIMA (autoregressive integrated moving average) processes are not possible, given the abrupt shifts in oil prices experienced during the 1974–83 period.

Chart A

Indexes of the Three Series— The 18-Month Case

(SERIES MEAN FOR 1976-83 = 100)

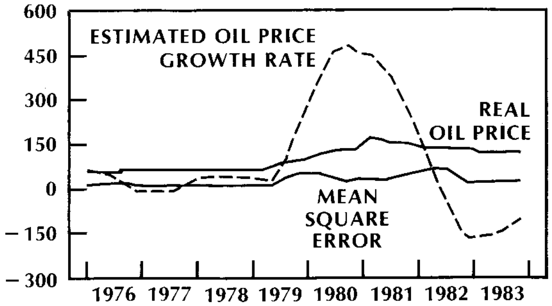


SOURCES OF PRIMARY DATA: U.S. Bureau of Labor Statistics.
U.S. Department of Energy.

Chart B

Indexes of the Three Series— The 24-Month Case

(SERIES MEAN FOR 1976-83 = 100)



SOURCES OF PRIMARY DATA: U.S. Bureau of Labor Statistics.
U.S. Department of Energy.

estimate r were run using the function

(B.2) $\ln(P_t) = a + rt + \varepsilon_t, \quad t = 1, \ldots, s,$

where s is the number of observations on the price variable used to estimate r.[4] 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 reestimating, a time series was generated.

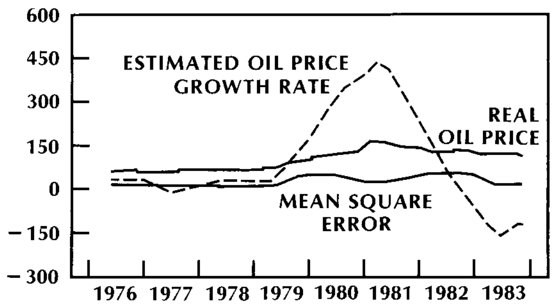
The data used in the regressions were seasonally adjusted monthly averages of the refiner acquisition cost of domestic crude oil over the 1974-83 period. Three period lengths, s, were used to estimate the growth rate and mean square error: 18 months, 24 months, and 30 months. The time periods were selected to preserve degrees of freedom while still providing sufficient observations to establish 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 formed using the 18 months, 2 years, and 2½ years before period s and the mean square error from those regressions.

Results of the procedure are presented in Charts A, B, and C 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 the constructed growth rate series exhibited more movement than real oil prices did during the 1979-83 period, when prices rose rapidly and then fell. The MSE terms increased during the period of rapidly rising prices and after 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

Chart C

Indexes of the Three Series— The 30-Month Case

(SERIES MEAN FOR 1976-83 = 100)



SOURCES OF PRIMARY DATA: U.S. Bureau of Labor Statistics.
U.S. Department of Energy.

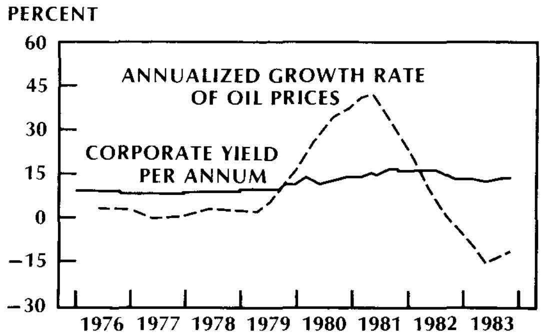
larger average MSE, as would be expected.

The relationship between the constructed growth rate series and alternative investments (which is assumed to be a proxy for the firm's discount rate that 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 D against the average yield on corporate bonds.

As shown in the chart, the expected growth rate of oil prices was considerably above the return on other investments between October 1979 and April 1982, although the difference between the series began to decrease in 1981. Not surprisingly, the rig count for the United States hit a record high in December 1981.

Chart D

Comparison of Estimated Growth Rate of Oil Prices from the 30-Month Case with Average Yield on Corporate Bonds



SOURCES OF PRIMARY DATA: Board of Governors, Federal Reserve System.
U.S. Bureau of Labor Statistics.
U.S. Department of Energy.

Racial Earnings Differentials in Texas

*By Alberto E. Davila**

Hispanic and black males have lower average earnings than white males in Texas. This difference has been well documented for the nation as a whole. Minorities in Texas, however, are at a greater earnings disadvantage relative to white males than are their counterparts in the United States and California (Table 1). The comparison between Texas and California is of interest because the two states have similar racial distributions. Adding significance to racial wage differentials in Texas is the fact that minorities account for a larger proportion of the population there than in the United States.

Why are earnings for Hispanics and blacks lower relative to those of whites in Texas? Why are these racial wage differentials larger in Texas than in the United States? One explanation is that the earnings difference reflects labor market discrimination against minorities, a form of discrimination that may be more widespread in Texas than in other states. An alternative explanation is that minorities in Texas have accumulated less education and experience relative to nonminorities in the state and their national counterparts.

In Texas, non-Hispanic white males have, on average, more education and a higher level of English proficiency than Hispanic males. These differences explain most of the earnings differential between Hispanics and whites in the state. In contrast, the educational advantage of whites over blacks explains only a fourth of the black-white earnings difference. For blacks the unexplained earnings differential has often been attributed to discrimination, but other factors not available for empirical analysis may also play a role in explaining the earnings difference. Whatever the explanation may be, however, the results from this article are similar to those found in studies that have researched racial wage differentials in the nation.[1]

* *Alberto E. Davila, formerly an economist at the Federal Reserve Bank of Dallas, is a member of the faculty of Tarleton State University. The views expressed are those of the author and do not necessarily reflect the positions of the Federal Reserve Bank of Dallas or the Federal Reserve System.*

1. For some recent treatment of racial earnings differentials in the nation, see Cordelia W. Reimers, "Labor Market

Table 1
SELECTED STATISTICS FOR MALES 16 AND OVER IN TEXAS, CALIFORNIA, AND UNITED STATES

	Texas	California	United States
Earnings difference for full-time workers (Percent)[1]			
Between non-Hispanic whites and Hispanics	41.3	34.9	27.9
Between non-Hispanic whites and blacks	37.2	25.7	24.9
As percent of population in 1982[2]			
Non-Hispanic whites	69.9	76.9	84.4
Hispanics	20.2	16.1	5.5
Blacks	10.4	7.0	10.1

1. Although based on median earnings, the U.S. estimates are consistent with those in national studies.
2. Percentages may not add to 100.0 because of rounding.
SOURCES OF PRIMARY DATA: U.S. Bureau of Labor Statistics.
U.S. Bureau of the Census.

Important policy implications, similar to those of national studies, can be drawn from these results. Most of the earnings difference between Hispanics and whites in Texas can best be addressed through policies designed to increase the level of education and English proficiency of Hispanics. Some of the earnings gap between blacks and whites in the state may also be narrowed by promoting education for blacks. Affirmative action programs could reduce some of the remaining earnings differential, but more research on the determinants of black earnings may unveil sources of this earnings gap that are not affected by labor market discrimination.

The data

This article uses data from the Public-Use Sample from the 1980 Census. The sample in the empirical analysis consists of males 16 years of age and over who worked at least 48 weeks in 1979. This sample was chosen because males who work full-time have steadier earnings through time than females and part-time workers, who on average have more erratic labor force participation patterns.

The earnings variable analyzed is measured on an hourly basis and is adjusted for differences in the cost of living. This procedure avoids earnings variations resulting from differences in hours worked in a year, as well as differences reflecting regional cost-of-living differentials. The 1980 Public-Use Sample includes the "usual hours worked per week in 1979" for each individual in the survey. Usual hours worked, coupled with the number of weeks worked in 1979, were used to transform annual earnings into hourly earnings. The Public-Use Sample also identifies the region where an individual lives. This information, along with cost-of-living indexes for each city, was used to calculate real earnings. Racial differentials in nominal wages could arise because of high concentrations of minorities in areas with low price levels.

Data for 1979 from the American Chamber of Commerce and the U.S. Bureau of Labor Statistics (BLS) were used to compute the cost-of-living indexes (Table 2).[2] The American Chamber of Commerce provides data on many small- and medium-

Discrimination Against Hispanic and Black Men," *Review of Economics and Statistics* 65 (November 1983): 570–79; and David Shapiro, "Wage Differentials Among Black, Hispanic, and White Young Men," *Industrial and Labor Relations Review* 37 (July 1984): 570–81.

Table 2
COST-OF-LIVING INDEXES FOR SELECTED TEXAS AND CALIFORNIA CITIES
(U.S. average = 1.000)

Texas cities	Index level	California cities	Index level
Abilene	.921	Anaheim-Santa Ana-Garden Grove	1.027
Amarillo	.879		
Austin	.931	Bakersfield	1.001
Beaumont-Port Arthur-Orange	.957	Fresno	1.042
Brownsville-Harlingen-San Benito	.952		
		Los Angeles-Long Beach	1.078
Corpus Christi	.915		
		Modesto	.970
Dallas-Fort Worth	.957		
		Riverside-San Bernardino-Ontario	.975
El Paso	.926		
		Sacramento	1.075
Galveston-Texas City	.962	San Diego	1.048
		San Francisco-Oakland	1.113
Houston	.987	San Jose	1.038
		Santa Barbara-Santa Maria	1.039
Laredo	.887	Santa Rosa	1.012
Lubbock	.942	Stockton	.970
McAllen-Pharr-Edinburg	.945		
Midland	.985		
Odessa	.989		
San Angelo	.936		
San Antonio	.913		
Waco	.842		

SOURCES OF PRIMARY DATA: American Chamber of Commerce.
U.S. Bureau of Labor Statistics.

2. The American Chamber of Commerce cost-of-living data were obtained from a research paper I coauthored with J. Peter Mattila ("Do Workers Earn Less Along the U.S.-Mexico Border?" *Social Science Quarterly*, forthcoming). Five cities did not have cost-of-living data from either the BLS or the American Chamber of Commerce—San Angelo, Galveston, Laredo, Santa Barbara, and Santa Rosa. Estimates for these cities were generated from regressions using data for cities in the sample with cost-of-living estimates. A host of characteristics from the cities with reported cost-of-living data, ranging from population to per capita income, were used as independent variables. The estimated model was used to predict the cost of living of the five remaining cities.

size cities that are not covered by the BLS. For some large cities, cost-of-living data were available from both the BLS and the American Chamber of Commerce. Because of their greater reliability, the BLS indexes were used for the larger cities. The gap between both cost-of-living estimates for the large cities, however, had to be used to adjust the indexes for the cities covered only by the American Chamber of Commerce. This adjustment made the data from the two sources comparable across cities.

Characteristics of workers

Individuals who invest in schooling and accumulate work experience have higher earnings. Overwhelming empirical evidence supports this relationship. A body of theory that regards the skills acquired through education, training, and experience as "human capital" has received widespread acceptance. More recent work has shown that in addition to education and experience, the ability to speak English and the number of years a foreign-born individual has worked in the United States are also positively related to higher earnings.

There are several alternative theories about the importance of English proficiency in the labor market.[3] One theory suggests that English fluency can be treated as an economic good, much like education and experience are treated in a human capital model. According to this theory, individuals invest in education—in this case, English proficiency—to increase their productivity in the labor market. The increased productivity enables the individuals to command higher wages.

This human capital theory is intuitively appealing. It is easy to see how some individuals in service occupations can increase the value of their output by enhancing their ability to speak English. But the value of English fluency is not confined to service occupations. Narrowing communication gaps between management and labor, for example, may also serve to increase production in manufacturing firms.

An alternative theory suggests that economies of scale in the acquisition of information are generated around English-speaking communities. As a result, individuals with lower levels of English proficiency are at a relative disadvantage in acquiring labor market information. Individuals with lower than average English proficiency levels, then, are less likely to find the highest-paying jobs suited to their qualifications.

Country of birth is another important determinant of earnings. Research has shown that after migrating to the United States, foreign-born males initially earn less than natives with similar characteristics. Such difference in earnings, however, narrows and approaches zero after 10 to 15 years of residence in this country.[4] The literature has theorized that the initial earnings differential reflects differences between foreign countries and the United States in the quality of education, as well as high returns from information acquired by natives because of long residence in their community. Hispanics are more likely to have been born abroad than whites, so it is important to control for earnings differentials arising from differences in nationality and the years worked in the United States.

As shown in Table 3, minorities in Texas have less education than whites, but they have roughly similar work experience (computed as age less education less 5). White males have, on average, about four more years of schooling than Hispanics in Texas. A similar pattern is found in California. Likewise, white males have about two more years of schooling than black males.

Also important in Texas is the difference in the levels of English proficiency of Hispanics and non-Hispanics. The 1980 Census asked surveyed individuals to rank their ability to speak English if they spoke a language other than English at home. As expected, more Hispanics in Texas and California spoke another language at home than did non-Hispanics. Non-Hispanics were more likely to speak an additional language in California (11 percent versus 6 percent) than in Texas. A higher concentration of Asians in California probably accounts for most of this difference.

3. Two recent articles discussing the role of English proficiency in the labor market are Gilles Grenier, "The Effects of Language Characteristics on the Wages of Hispanic-American Males," *Journal of Human Resources* 19 (Winter 1984): 35–52; and Walter McManus, William Gould, and Finis Welch, "Earnings of Hispanic Men: The Role of English Language Proficiency," *Journal of Labor Economics* 1 (April 1983): 101–30.

4. See Barry R. Chiswick, "The Effect of Americanization on the Earnings of Foreign-born Men," *Journal of Political Economy* 86 (October 1978): 897–921.

Table 3
MEANS OF SELECTED CHARACTERISTICS OF NON-HISPANIC WHITES, HISPANICS, AND BLACKS IN TEXAS AND CALIFORNIA

	TEXAS			CALIFORNIA		
	Non-Hispanic whites	Hispanics	Blacks	Non-Hispanic whites	Hispanics	Blacks
Logarithm of hourly wages						
Nominal	2.05	1.56	1.64	2.10	1.70	1.82
Real	2.09	1.63	1.67	2.05	1.64	1.75
Skill factors						
Years of schooling	13.67	10.01	11.85	13.88	10.42	13.01
Years of work experience	19.30	20.52	20.09	20.46	19.25	19.17
Percent speaking English						
Only	94.7	7.9	94.9	89.0	20.4	94.6
Very well	3.6	46.3	4.0	7.0	33.5	3.7
Well	1.2	27.1	.9	2.8	20.5	1.6
Not well	.5	18.7	.2	1.2	25.6	.1
Percent married	74.1	73.3	63.4	67.7	69.8	59.6
Percent U.S. citizens	96.2	72.2	97.2	88.6	49.0	97.0
Percent in occupation						
Professionals	31.6	10.4	11.1	33.0	10.8	17.0
Technical, sales workers	25.4	16.7	15.2	24.0	13.7	22.1
Service workers	5.7	10.4	14.9	7.7	12.1	17.1
Farm workers	.6	3.6	1.2	1.2	5.2	.9
Craftsmen	21.8	24.5	19.2	19.4	22.8	16.5
Laborers	14.9	34.4	38.4	14.7	35.4	26.4
Immigration[1]	10.94	17.14	10.80	12.61	24.21	10.75
Number in sample	6,076	1,622	847	12,786	2,475	1,054

1. The immigration variable was coded using seven categories. Natives were given a value of 6. More recent immigrants were assigned progressively higher codes, up to a maximum value of 47.5 for individuals with the least time in the United States.

SOURCE OF PRIMARY DATA: Public-Use Sample from the 1980 Census.

Close to half of the Hispanic males who reported they spoke another language at home ranked their English fluency below the "very well" category in both Texas and California. On the other hand, blacks and non-Hispanic whites in both states who spoke an additional language were much more likely to speak English very well.

Finally, a higher concentration of Hispanics were immigrants. More Hispanics than non-Hispanics were born abroad, as evidenced by the citizenship and immigration variables for both states. More Hispanics in Texas reported being U.S. citizens than in California.

Occupational distributions

The 1980 Census shows significant earnings differences across occupations. Earnings for professionals were much above those of laborers with similar racial and socioeconomic characteristics in Texas, ranging from 13 percent for black males to 23 percent for Hispanic males. Laborers, in turn, earned more than farm workers. Hispanic farm

Box A

The Decomposition Technique

Wage differentials can arise from differences in the returns from labor market skills and from differences in factor endowments. These two effects can be isolated by using earnings functions.[1] In particular, earnings functions can be written for two worker groups, a and b, as follows:

$$W_a = A_a + X_a B_a. \tag{1}$$

$$W_b = A_b + X_b B_b. \tag{2}$$

For both groups, W is the logarithm of wages, X is a vector of observed characteristics, and B is a vector of estimated coefficients. The difference in wages between groups A and B, $(W_a - W_b)$, can be decomposed into

$$R = (A_a - A_b) + X_b(B_a - B_b) \tag{3}$$

and

$$E = B_a(X_a - X_b). \tag{4}$$

R is the difference in wages reflecting differences in returns to factor endowments. It is obtained by assuming that both groups have the same factor endowments, X_b, and by allowing for variation in the returns to these factor endowments: $(A_a - A_b)$ and $(B_a - B_b)$. For example, the estimated schooling coefficients from the earnings equations for Hispanics and whites in Texas were .03890 and .05743, respectively. Using the average schooling years for Hispanics (group b) of 10.006, equation 3 can be written as

$$\begin{aligned} R_{EDUCATION} &= 10.006 \times (.05743 - .03890) \\ &= .1854. \end{aligned} \tag{5}$$

Multiplying this number by 100 yields the 18.54-percent earnings difference between Hispanics and whites in Texas attributed to the differences in returns to factor endowments reported in Table 4. The same procedure is applied to each of the remaining factors, yielding the total earnings difference attributable to factor return differentials at the bottom of Table 4.

E is the difference in wages reflecting differences in factor endowments. In this case, the returns to factor endowments are assumed the same for both groups (B_a), leaving a wage difference reflecting differentials in factor endowments: $(X_a - X_b)$. Whites in Texas have an average education of 13.676 years. Using this figure, along with the above information, yields

$$E = .05743 \times (13.676 - 10.006) = .2108. \tag{6}$$

Factor endowment differences in schooling account for 21.08 percent of the earnings differential between Hispanics and whites in Texas.

1. This technique is explained by Ronald Oaxaca, "Male-Female Wage Differentials in Urban Labor Markets," *International Economic Review* 14 (October 1973): 693–709.

workers, for example, earned 34 percent less than Hispanic laborers.[5] Consequently, to the extent that minorities are more concentrated in low-skill occupations, earnings differences could exist because of racial differentials in occupational mixes in Texas.

Table 3 shows that differences in occupational distributions among races do exist in Texas. Compared with Hispanic and black males, white males were more concentrated in white-collar occupations. Among blue-collar workers, Hispanic males were more likely to be farm workers than were white and black males.

Whites and Hispanics in Texas and California had similar occupational distributions in 1980. A larger share of white males were concentrated in white-collar occupations than in blue-collar jobs in both Texas and California, while more Hispanic males were in blue-collar occupations in those states. Blacks, however, were more likely to be in white-collar jobs in California than in Texas.

Decomposing racial earnings differentials

Racial earnings differentials can be decomposed

5. These occupational earnings differentials were obtained from the earnings functions generated to calculate the results in Table 3. The relevant coefficients were adjusted by $[1 - \exp(b)] \times 100$, where b is the coefficient. The regression coefficients of a semilogarithmic function, when large, overestimate differentials.

into differences resulting from characteristics of workers (such as schooling) and into differences from the returns to characteristics. (See Box A.) To do so, however, earnings functions must first be estimated for each racial group. In addition to some of the variables already mentioned above, these earnings functions include measures of marital status, physical disability, and the concentration of Hispanics or blacks in a city. The logarithm of hourly earnings is used in these functions as the dependent variable.

The specification of the earnings function differs from specifications in similar studies in two major ways. First, the cost-of-living measure used to deflate nominal earnings is superior. Most other studies have used cruder cost-of-living estimates, such as BLS estimates for nearby cities.[6] An attempt was made in this study to use a more comprehensive cost-of-living measure. Second, while other studies have assumed that English proficiency affects Hispanic earnings only, the study here takes a broader view and assumes that earnings of both blacks and whites also are affected by their ability to speak English.[7] This approach proved to be especially useful in the earnings equations for non-Hispanic whites. The number of non-Hispanic whites who reported speaking an additional language at home is sufficiently large for the statistical analysis. Nearly all the blacks in the sample, however, spoke only English.

The majority of the estimated coefficients in the earnings functions have the expected sign and are statistically significant. (The estimated earnings functions for Texas are shown in the Appendix.) The variables for U.S. citizenship and years since migration to the United States have coefficients with unexpected signs in some instances. For example, the results imply that U.S. citizens, other things the same, earn less than noncitizens. But for the most part, these coefficients are not statistically significant. In addition, an explanation that has been offered for similar findings is that the average foreign-born individual living in this country is more highly motivated than native-born U.S. citizens and the motivation leads to higher earnings.

The earnings functions were also estimated using nominal earnings, instead of real earnings, as the dependent variable. The coefficients of these estimated functions show no significant changes from those using real earnings. Consequently, any problem associated with the cost-of-living estimates likely did not bias the overall results presented here.

The significance of using real rather than nominal earnings, however, can be seen in Table 3. Much of the earnings differential between a given racial group in California and Texas disappears once cost-of-living differences are taken into account. California has, on average, a higher cost of living than Texas.

Differences in characteristics of workers

Table 4 shows how much of the racial earnings differentials can be explained by different levels of factor endowments. The Hispanic-white earnings differential in Texas is mostly explained by differences in personal characteristics of Hispanics and whites. Education is the major source of the difference in earnings, followed by English proficiency. As expected, the concentration of Hispanics in blue-collar occupations also accounts for a sizable portion of the differential.

Only a small share of the black-white earnings differential in Texas can be explained by differences between blacks and whites in factor endowments. Still, education plays a role in accounting for close to one-fourth of this differential. The occupational mix is the second largest source explaining the income difference. In California the occupational distribution is the most important determinant of the black-white earnings gap, while education accounts for a small part of the differential.

Differences in returns to characteristics

Differences in returns to worker characteristics are conventionally interpreted as measures of the extent to which the earnings differential is attributable to labor market discrimination. This is not to say, however, that this method of measuring discrimination accounts for all kinds of discrimination. It is

6. Some recent articles using cost-of-living data for nearby cities include Reimers, "Labor Market Discrimination Against Hispanic and Black Men," and Shelby D. Gerking and William N. Weirick, "Compensating Differences and Interregional Wage Differentials," *Review of Economics and Statistics* 65 (August 1983): 483–87.

7. Grenier, for example, assumes that the earnings of non-Hispanic whites are not affected by their ability to speak English.

Table 4
DECOMPOSITION OF RACIAL WAGE DIFFERENTIALS IN TEXAS AND CALIFORNIA BY DIFFERENCES IN FACTOR ENDOWMENTS AND RETURNS TO FACTOR ENDOWMENTS

	TEXAS				CALIFORNIA			
	Hispanic-white differential		Black-white differential		Hispanic-white differential		Black-white differential	
	Percent explained by		Percent explained by		Percent explained by		Percent explained by	
	Factor endowment	Returns to factor endowment	Factor endowment	Returns to factor endowment	Factor endowment	Returns to factor endowment	Factor endowment	Returns to factor endowment
Regression intercept		-14.78		48.69		-48.25		23.74
Years of schooling	21.08	18.54	10.47	-2.60	16.08	17.79	4.04	-31.18
Years of work experience	-.14	3.30	-.41	12.47	-.28	9.52	.45	-2.17
English ability	5.86	1.57	-.04	-.45	9.00	-5.57	-.56	.40
Married	.16	3.89	2.18	2.22	-.43	5.78	1.62	6.10
U.S. citizenship	.41	-2.00	-.02	-34.64	-1.55	4.73	.33	19.02
Occupation	7.16	-1.71	7.47	2.70	5.84	1.87	5.04	2.12
Years since migration to United States	1.38	-5.86	-.03	-8.74	5.02	10.26	-.81	.29
Disabled	-.10	-.60	.05	.25	-.17	.01	0	-.38
Concentration								
Hispanic	8.19				10.54			
Black			1.45				.65	
$\ln(W_a) - \ln(W_b)$[1]	46.36		41.00		40.18		29.08	
$(A_a - A_b) + X_b(B_a - B_b)$		2.36		19.90		-3.87		18.32
$B_a(X_a - X_b)$	44.00		21.10		44.05		10.76	

1. Difference may not match that in Table 3 because of rounding.
NOTE: The earnings functions include the variables in Table 3.
SOURCE OF PRIMARY DATA: Public-Use Sample from the 1980 Census.

possible that minority groups have been crowded into low-paying jobs because of discrimination. This kind of discrimination is often called occupational discrimination. The results presented here show that differences in occupational distributions do explain some of the racial earnings differentials, but they do not identify the determinants of the occupational distributions. Thus, the possibility of occupational discrimination is not addressed.

In theory, the attitudes of both employers and consumers might lead to discrimination in hiring. According to one model, some firms have a "taste" for discrimination, leading them to hire minority workers at a lower wage than nonminority workers. In the discrimination model here, the wage difference between minorities and nonminorities is also a function of the concentration of minorities. (See Box B.) Given a downward sloping demand curve for minorities relative to nonminorities (reflecting the distaste for hiring minorities), an increase in the minority population leads to lower relative wages for the discriminated group.

To test whether the number of minorities in a region actually affects wages, the earnings functions reported here also contain a variable that measures the concentration of Hispanics and blacks in a region. The coefficient for the concentration variable is negative (meaning higher concentrations

Box B

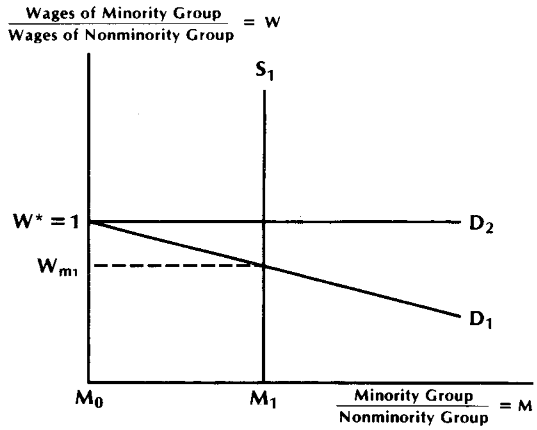
A Discrimination Model

Figure 1 shows a graphical representation of a discrimination model.[1] The demand curve in a discriminating labor market is D_1. The proportion of minority workers to nonminority workers is equal to S_1. Minority workers are paid a fraction, W_{m1}, of nonminority wages. W_{m1} is less than 1 because of the "taste" for discrimination (d) in the labor market. Formally, assume the value of the marginal product of minority workers (VMP_m) is equal to the value of the marginal product of nonminority workers (VMP_{nm}). Wages of nonminority workers equal VMP_m, but the wages of minority workers are equal to $VMP_m/(1 + d)$. Because d is positive, then, the wages of minority workers are less than those of nonminority workers.

An additional property of this model is that racial wage differentials between two groups could arise because one group is relatively more abundant than the other, even though firms have the same discrimination taste for both. If the proportion of workers in race A is M_0 and the proportion of workers in race B is M_1, race B is at a greater earnings disadvantage relative to nonminorities than is race A. This same argument applies for the relative earnings of a race in two cities, where the wage gap will be greater in cities with a higher concentration of the minority workers. The proportion of minority workers does not have an effect on relative wages if the labor market's discrimination taste is zero; in that case the demand curve is D_2.

Figure 1

Relative Wages and Concentrations of Minorities



1. This theory is attributed to Gary S. Becker, *The Economics of Discrimination* (Chicago: University of Chicago Press, 1957). For an overview of this and other discrimination theories, see Robert M. Fearn, *Labor Economics: The Emerging Synthesis* (Cambridge, Mass.: Winthrop Publishers, 1981), 167–74.

of minorities lower relative earnings) in all regressions for blacks and Hispanics, but this variable is only significant in the earnings regressions for Hispanics.

The regression results for Hispanics, however, are inconsistent with the discrimination model. The results in Table 4 suggest that Hispanics are not discriminated against in the labor market, because the earnings differential not accounted for by differences in characteristics between Hispanics and whites is close to zero. The implication is that after taking account of the proportion of Hispanics in the labor market, the demand curve for Hispanics in the discrimination model has no slope. But the negative effect on the Hispanic concentration coefficient suggests that this demand for Hispanics is downward sloping. An explanation for the apparent inconsistency is that the Hispanic concentration measure captures other effects that are not related to labor market discrimination. These effects have received some attention recently in the literature.[8]

Omitted variables

Despite the attraction of measuring labor market discrimination, empirical techniques still suffer from econometric problems. The earnings functions, for example, may exclude important factors that might help explain some of the earnings difference other-

8. See, for example, George J. Borjas, "The Substitutability of Black, Hispanic, and White Labor," *Economic Inquiry* 21 (January 1983): 93–106.

wise attributed to discrimination in the labor market. This "omitted variable" problem, when it exists, has been shown to bias regression estimates.[9]

It is possible that the estimated earnings functions of this article exclude some important factors associated with earnings. For example, a recent study shows that some of the earnings difference between Mexican-Americans and non-Hispanic white college graduates can be partially explained by the higher grade point averages of whites.[10] A quality-of-education measure is not available from the 1980 Census, however, and was therefore excluded from the earnings functions reported here.

Nevertheless, the decomposition technique does serve to identify some of the major sources behind wage differentials. The results of this study provide insight into the determinants of racial earnings differentials in Texas and California. But it should be noted that more progress in the methodology of measurement, as well as more extensive data, would be helpful in estimating labor market discrimination.

Implications

The results presented in this article indicate that investment in education and English proficiency for minority groups, particularly for Hispanics in Texas, may help narrow racial gaps in earnings. In comparing Texas and California, it was found that there were no significant differences between the states in racial differentials in unadjusted real earnings. This finding is of interest because of the large discrepancies that appear by looking at unadjusted nominal differentials. These differences are accounted for by cost-of-living and educational attainment differentials between Texas and California.

Recent emphasis by the Texas government on promoting education is a policy well suited to increasing the earnings potential of minority groups in the state. A recent education bill is designed to give special emphasis to increasing the level of education of low-income districts in Texas. This is a particularly important feature in narrowing racial gaps in education because minorities are highly concentrated in a few low-income school districts in the state. A large number of blacks live in inner cities, away from the more affluent suburbs. Similarly, a large share of the Hispanic population is located along the Texas-Mexico border. This region has the lowest income level in the state.

The results from this study could be interpreted as indicating that affirmative action programs are an alternative for increasing earnings for blacks. Such a possibility should not be dismissed altogether, but the black-white earnings difference, in particular, warrants further research.

9. See, for example, Henri Theil, *Principles of Econometrics* (New York: John Wiley & Sons, 1971), 549–52.

10. See Larry E. Penley, Sam Gould, and Lynda Y. de la Viña, "The Comparative Salary Position of Mexican American College Graduates in Business," *Social Science Quarterly* 65 (June 1984): 444–54.

Appendix

ESTIMATED EARNINGS FUNCTIONS FOR TEXAS, BY RACE

	Non-Hispanic whites		Hispanics		Blacks	
Factor	Coefficient	*t* statistic	Coefficient	*t* statistic	Coefficient	*t* statistic
Constant	.58	4.87	.73	5.00	.09	.17
Schooling	.06	16.68	.04	6.80	.06	4.82
Work experience	.04	20.90	.04	9.27	.03	4.72
Work experience squared	-.001	-15.68	-.0004	-6.59	-.0005	-3.77
English spoken						
Very well	-.03	-.67	-.03	-.52	-.06	-.39
Well	-.10	-1.29	-.12	-1.72	.43	1.40
Not well	-.10	-.85	-.16	-2.04	.18	.30
Marital status	.20	10.32	.15	3.85	.17	2.60
U.S. citizenship	.02	.21	.04	.59	.36	.92
Occupation						
Professional	.21	7.47	.26	4.08	.13	1.24
Technical, sales worker	.09	3.55	.15	2.95	-.01	-.14
Service worker	-.18	-4.70	-.20	-3.54	-.19	-2.03
Farm worker	-.46	-4.61	-.42	-4.69	-.38	-1.41
Craftsman	.11	4.37	.13	3.12	.10	1.24
Years since migration to United States	-.002	-.73	.001	.43	.01	.46
Physical disability						
Limits work	-.10	-2.46	.07	.79	-.17	-1.14
Prevents work	-.05	-.29	.34	.50	.10	.19
Concentration						
Hispanic			-.23	-3.39		
Black					-.08	-.20
R^2	.25		.19		.11	

1984 Economic Review

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