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THE IMPACT OF A DEPLETABLE RESOURCE ON A RURAL AREA*

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Introduction

The past decade has seen an abundance of research concerning the socioeconomic impact of rapid economic development of sparsely populated, rural areas.[1] Much of this research has been spurred by plans for production of coal and synthetic fuels combined with government environmental impact statement requirements. During the same time, little attention has been devoted to the study of the eventual decline of areas whose economy is based in large part on the exploitation of depletable natural resources. This is an eventuality which may be faced by the types of areas mentioned above. The purpose of the High Plains — Ogallala Aquifer (HP/OA) study, recently funded by the Department of Commerce, is to study the regional impact of the decline and exhaustion of the water aquifer and the area's oil and gas resources. The study also was designed to determine impact ameliorating strategies. [Banks (3)].

The first part of the HP/OA study is forecasting the future use of water from the aquifer on a state by state basis. This forecast is derived from estimates of future subregional agriculture patterns and future subregional production of energy. (Subregional refers to the portion of a state whch overlies the Ogallala aquifer.) The second part of the study involves aggregation of state subregional forecasts and analysis of possible future socioeconomic impacts under several possible water management alternatives and macroeconomic scenarios concerning crop and energy prices.

The research described in this paper reports the impacts of oil and gas depletion in the Ogallala aquifer portion of the state of Oklahoma. This is a ten county rural area in Western Oklahoma.[2] The area is described in section 2 below. The results do not take into account the additional impacts from the depletion of the aquifer, nor do they contain interactive or synergistic effects of simultaneous depletion of oil and gas and water.[3] Actually, the model and results are developed as inputs for a more general study, but themselves represent important findings

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[1] For example see Krutilla [1] and Vander Mullen [2].

[2] The counties are: Beaver, Beckham, Cimarron, Dewey, Ellis, Harper, Roger Mills, Texas, Woods, and Woodward.

[3] An interesting and useful area of research is suggested here in developing an optimal depletion model of two different exhaustible resources that interact with each other through their areal extent, as inputs in each others production function, and as common inputs in the area's major productive activity-agriculture.

concerning the behavior of the energy industry in a rural area, specifically the Oklahoma high plains.

The general problem of the efficient use of depletable resources has been subject to intensive research recently. From the seminal contributions of Gray [4] and Hotelling [5], a body of theory has been developed as exemplified by Gordon [6], Burt and Cummings [7], Weinstein and Zeckhauser [8], and Peterson [9], and is now contained in a textbook by Dasgupta and Heal[10]. This theory has been used in empirical applications by Fisher [11], MacAvoy and Pindyck [12], Cox and Wright [13], and Bradley [14]. The applications rely on geological and engineering information combined with econometric techniques to produce empirical results.

With the exception of Bradley [14], the applied research is directed to problems at the national level of aggregation based on industry or state level data. Bradley developed a very detailed financial/geological/engineering model of a specific open-pit copper mine in Canada. The current paper is directed at a level of aggregation — ten counties — not generally approached. Further, it uses the results to determine impacts at this level. This level is small enough to capture the unique characteristics of the energy industry in this particular area without sacrificing the scope needed to produce usable data series for econometric analysis, as is the case when focusing on an individual deposit. The multi-county level of analysis presents unusual problems of data collection because much of the desirable information about the oil and gas industry is available only at the state or national level (e.g. proved reserves and expenditures on exploratory drilling).

The next section of the paper gives a description of the ten county area studied. Section three explains the model used, the development of estimating equations, the econometric estimation, and the data collected and developed. Section four relates the estimation results and forecasts for oil and gas production as well as area income and employment and the methods used to predict income and employment. The next section is a policy analysis which stimulates the price of oil and gas necessary to keep output constant to 2020. The final section is a summary and set of policy conclusions and suggestions.

Description

The ten county area used as a case study in this analysis is located in the western part of Oklahoma. The counties are honogeneous in both geographic and economic characteristics. The nearest metropolis is Amarillo, Texas with a population of 132,000 and there is no town larger than 9,000 in the area. The total population of the area is 98,600 and has experienced only an eight percent increase over the last decade.

The largest employer is agriculture. There are no manufacturing employers with more than 25 persons per establishment. Measured unemployment has been historically low, typically below four percent due primarily to the stability of agricultural employment and the difficulty of measuring unemployment and underemployment in family farming activities. Employment has increased 16 percent from 1970 to 1979 while farm income has increased 57 percent.

The area is relatively isolated with few new job opportunities for the residents or potential migrants. From 1970 to 1976 average net migration was only 1.4 percent with three counties experiencing significant net out-migration.

It would be difficult, however, to describe the area as economically depressed. Per capita income in each county is typically higher than the Oklahoma average and in several counties, significantly so. Coupled with the very low measured unemployment rates, the area is currently economically properous.

The foundation of this prosperity is, however, built upon two depletable resources, water and petroleum. Non-farm income, made up primarily of petroleum related activities, comprised 65 percent of total income in 1979. Further, agriculture relies heavily on petroleum resources to supply energy for irrigation. As petroleum and water in the Ogallala aquifer are depleted over the next several decades there will be serious readjustment required to maintain the standard of living in the area. The next section of this study provides the methodology used to generate forecasts of the depletion of the petroleum resources in the area.

Model

The purpose of this section is to describe the theoretical and statistical models used to predict crude petroleum and natural gas production in the ten county area of Oklahoma that overlies the Ogallala aquifer. The general methodology for developing the equations used to make forecasts was to maximize the confidence of the forecasts possible with the statistical model, consistent with economic theory. Operationally, a step-wise linear regression technique was used to develop the statistical model using the criterion that the model would explain the maximum possible variation in the dependent variable; oil or gas production, respectively. No limitations were placed on the fundamental form of the equations. Economic theory was invoked on the signs of the parameter estimates, where appropriate.

Before describing the statistical models in detail, certain characteristics of the data that limit econometric techniques must be discussed. First the series for both petroleum and gas production were limited to approximately thirty years. This series is truly complete in that it captures all production beginning with the first discovery wells in the area. From a statistical perspective, however, this is a short time-series, providing only the bare minimum degrees of freedom for estimating purposes. This results, of course, in relatively unstable parameter estimates severely limiting the number of independent variables that can be included and increasing the range of the confidence intervals.

A particular problem, peculiar to estimating petroleum or gas production, of the limited time-series, is the inability to include long time lags between such variables as output and price and output and previous output. Economic theory would suggest that because of the large investment required for exploration and development activities in the energy industry there would be long lags between changes in price and output. In order to maintain appropriate degrees of freedom, the length of the time lag in prices and output was limited to five periods.

A second problem in developing these models results from the fact that only a very specific geographic area is being studied. While the ten counties in Oklahoma that overlay the Ogallala aquifer produce a significant amount of crude oil and natural gas, the total production over time from these reserves is clearly limited. Further, many of these fields are relatively old, dating to the late 1950's and early 1960's. It is thus expected that exploration activities would move to other geographic regions and that reserves would be depleted in this study area rather than maintained at a constant ratio with output or enhanced.

A third general problem in modeling petroleum and gas production is in the definition of output. Specifically, output from oil wells frequently includes casinghead gas. In some of the earlier years, this product may actually have been flared.

The definition of output for oil wells that also produce casinghead gas had to be clarified. The choice in this case was to aggregate dry gas and casinghead gas together.

Within the limitations outlined above, it is, nevertheless, possible to develop statistically sound estimating equations upon which predictions may be based. Separate equations were developed for petroleum production and for gas production. As discussed above, gas production included casinghead gas from oil wells because of data limitations.

The result of step-wise linear regression generated the following statistical models of petroleum and natural gas production. The absolute values of the t-statistics are in parentheses. The definition of the variables are provided in Appendix A.

The variables included in the analysis and their theoretical relationship to output are:

Time (T), where it is assumed that overtime, more output will be produced due to more extensive drilling and better technology.

Time squared (T^2) was included to capture the possible affect that because a given geographic area was being studied there would be declining production as the fields increased in age. The a priori sign of this variable is thus assumed negative.

A lagged price variable was included in each equation (POILI5 for the oil equation and PGASI1 for the gas equation). The projected sign of this variable is, of course, positive.

Lagged production was also included in each equation, R2OIL and R3GAS for the oil and gas equation, respectively. They were included to capture the effects of previous production and future exploratory activity. Higher levels of previous production would induce greater activity, but would also mean less available because of the fininte reserves of the area. The sign of this variable is thus ambiguous.

A depth variable (DEPTH) was included to indicate the increasing costs of future exploratory activity. Drilling to greater depths in the future would inhibit production because of the increasing costs. It is assumed that the sign of this variable would be negative.

Crude Petroleum Equation:

$$(1)\ \text{TOTOIL} = \underset{(2.53)}{.207}\ \text{E7 T} - \underset{(2.62)}{51939}\ \text{T}^2 - \underset{(2.54)}{3748}\ \text{DEPTH}$$

$$+ \underset{(4.08)}{.670}\ \text{R2OIL} + \underset{(1.26)}{.238}\ \text{E7 POILI5}$$

$$\bar{R}^2 = .88;\ F_{(4,19)} = 43;\ N = 24$$

Natural Gas Equation:

$$(2)\ \text{TOTGAS} = \underset{(8.28)}{-.794}\ \text{E9} + \underset{(9.39)}{.116}\ \text{E9 T} - \underset{(11.52)}{.274}\ \text{E7 T}^2$$

$$+ \underset{(3.78)}{.309}\ \text{E9 PGASI1} + \underset{(3.17)}{.373}\ \text{R3GAS}$$

$$\bar{R}^2 = .98;\ F_{(5,14)} = 317;\ N = 20$$

Both equations more than adequately meet the criterion of high R-squared (adjusted) values and have the theoretically expected signs for the explanatory variables. In both equations the price variable, indexed to 1977, exhibits the theoretically expected positive relationship with output. In the oil equation the t-statistic indicates that the estimated parameter was not significantly different from zero. This may be the result of a high degree of multicollinearity in the equation. The coefficient, however, has a t-statistic greater than unity indicating that the variable adds to the explanatory power of the overall equation.

In modeling petroleum production, it was found that a five year lag in prices had the highest explanatory power, while for gas production a one year lag for price added most to explaining production. Various other lag structures for prices were tested and the results presented are those which will statistically generate the predictions with the highest precision.

The DEPTH variable did not provide any increase in the explanatory power of the gas model although it was significant in the petroleum model. The results indicate a significant negative relationship between depth and petroleum production which is what would be expected from economic theory.

Two variables that show impacts on the time path of output levels are T and T^2. In both models, time and time squared have statistically significant coefficients. The results confirm that, for both petroleum and gas production in this area, an inverse parabola with respect to time provides an excellent fit to the data. This indicates that production levels will rise in the future, but at a decreasing rate, and eventually will decline. It is projected that, given the price series used in the HP/OA study petroleum production will reach zero in 2004.[4] For gas production the projected year for zero production is approximately 1998. Of course, a different price series or renewed exploration in significantly deeper zones may alter these projections.

Forecasts of oil and gas production are graphically presented in Figures 1 and 2. In Figures 1 and 2 the 1978 level of output is indicated as Q_{78}. Three output forecasts are presented, representing the simple least squares projection, $\hat{Q}$, and the upper and lower bounds of a 95 percent confidence band, Q_u and Q_L.

The forecasted level of energy production and its potential impact on the economy of the study area reveal that energy's role in the future of the area will decline in importance. These results assume of course that no major changes will occur in energy technology and that energy policies as they now exist will not be significantly altered. The assumption is also made that price forecasts which are based on current knowledge will prevail during the ensuring 40 years. The production of crude petroleum has declined steadily in the area since 1969 to a level of less than 15 million barrels annually. Much of this decline has been due to producers' interest in the development of natural gas resources at deeper levels than those in which crude petroleum is found. Thus, in some instances deposits of oil have been by-passed in favor of tapping the more lucrative gas deposits.

The outlook for the production of crude petroleum is for a reversal of the current downward trend with increases in output most likely to reach 65.1 million barrels by 1990. After that year, however, production is expected to decline sharply to a relatively insignificant level sometime after the year 2000.

[4] This time series was developed for use in the HP/OA study by the prime contractor Black and Veatch Consulting Engineers, as of April 1, 1980. The price path is reproduced on Figure 4 and 5 and labeled O_1 and G_1.

Figure 1. Oil Forecast: $\hat{Q}$, Q_u, Q_L; Constant 1978 Level: Q_{78}.

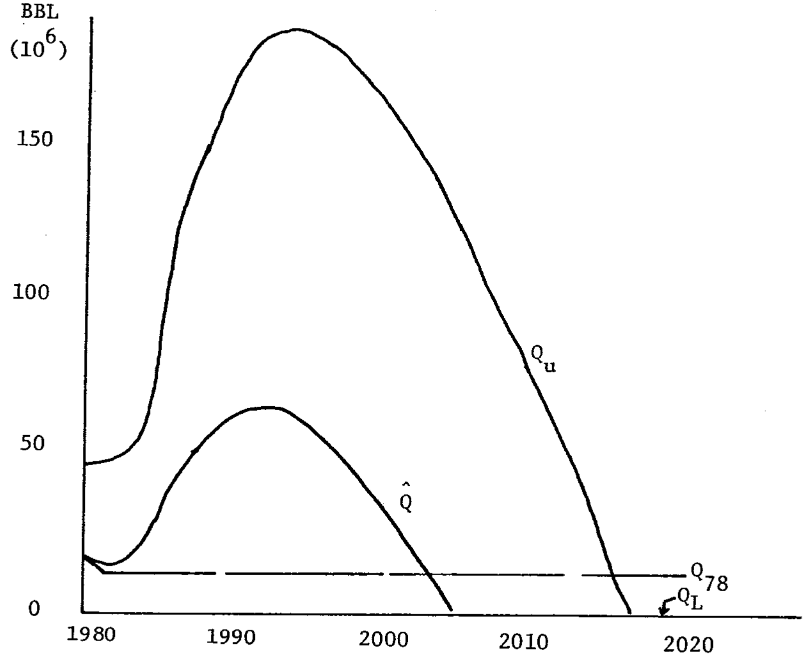
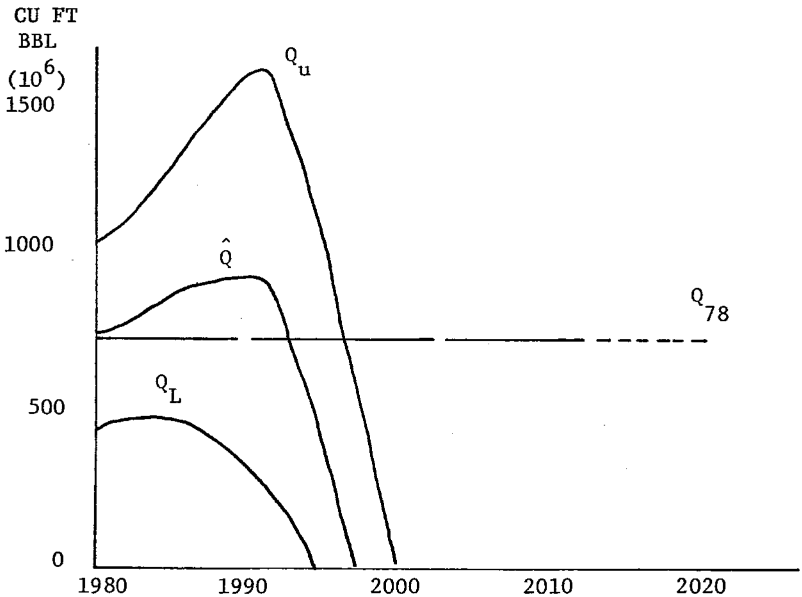


Figure 2. Gas Forecast: $\hat{Q}$, Q_u, Q_L; Constant 1978 Level: Q_{78}.



The production of natural gas in the ten county study area has fluctuated widely during the past decade from a high of 760.8 million cubic feet in 1972 to a low of 690.8 million cubic feet in 1976. Since 1976 however, the trend in production has been upward and exceeded 713 million cubic feet in 1978.

The outlook for natural gas production is not optimistic. The projected price structure of natural gas relative to that of crude oil apparently will divert much of the interest in natural gas now evidenced by the exploration companies to crude oil development. This could cause production of natural gas to decline rapidly during the next decade. The ultimate result of this down-turn will likely be a cessation of natural gas production shortly after 1990.

Forecasts for area employment and income are also calculated and are shown in Figure 3. In Figure 3 the level of employment is indicated by E and the level of income by I. Employment is a linear function of the value of oil and gas production. Income is the sum of wages and salaries paid to oil and gas employees, royalty payments to owners of oil and gas wells, and leasehold reservation payments to owners of potential oil and gas land. Details and the equations used to calculate employment and income directly related to oil and gas production are given in Appendix B.

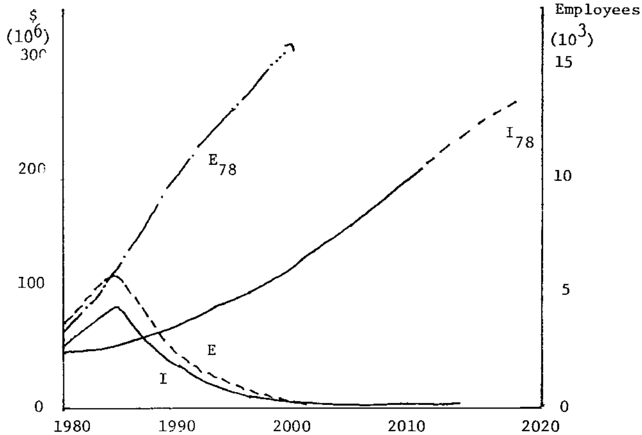
As would be expected, the outlook for area income and employment is similar to the outlook for area oil and gas production. As shown in Figure 3, both reach a peak before 1990 and then decline to a level below 1978 and continued to decline until oil and gas production stops. This decline will have a significant impact on the overall economy for the ten county area since approximately 65% of total income comes from petroleum related activities.

Policy Simulations

The forecasts of area oil and gas output, income and employment presented above (Figures 1, 2, and 3) depend upon only one policy variable — price. The other variables — time, depth and lagged output — are non-policy variables in the sense that they cannot be varied by the government. Price can be manipulated by various means such as direct controls, "wind-fall profits" taxes, etc. Manipulation of price may be used to influence producers' expectations about revenue from oil and gas output and thus indirectly manipulate total output and total revenue in order to influence the decline rate of area income and employment. In general, since total output is positively related to the price variable, policies which keep the price above the price path assumed for the above forecasts will increase output and push nearer the exhaustion date and policies which hold the price lower will decrease project output increases and slow the decline rate thereby lenghthening the time to exhaustion. The effects on income and employment depend on the actual output path and price path.

As a straightforward policy approach, the effects on area income and employment are simulated for the case in which output is constrained to the 1978 level. A policy to hold output constant can be implemented by influencing the production decisions of the oil and gas industry in the area. This is accomplished by altering expectations of producers concerning future prices. Determination of the price path which will produce this behavior is based on the above statistical model of output behavior in relation to price changes. The resulting constant-output price path is used to determine area income and employment just as in the forecasts above. These results are presented in Figure 3. The constant output price path, and for comparative purposes the price paths used for the forecasts above, and

Figure 3. Income Forecast, I; Constant 1978 Output I_{78} (10^6\$) Employment Forecast, E; Constant 1978 Output E_{78} (1000's employees).



the prices predicted by the U.S. Department of Energy, and price paths which hold oil and gas output constant are shown in Figures 4 and 5.

It is interesting to note that the constant-output price (O_2) for oil is considerably below the Department of Energy's prediction for world oil prices (O_3) during this century, but crosses the forecast price path (O_1) twice during this period. This indicates that policy should be directed at moderating or reducing near term expected price increases but allowing a continuing smooth increase. Much the same policy applies to natural gas price in that it should be allowed to increase smoothly along present trajectory in order to stimulate continued gas production. Both constant output total income and total employment in the area are above the forecast levels. (See I_{78} and E_{78} on Figure 3.) It should be noted that employment levels are not realistic after 2000 because employment is related to the value of oil and gas, which increases very steeply after 2000 because of the price increases. However, even if area employment does not increase to this extent, the revenue used to pay wages and salaries in this model is still available and would accrue to other factors in the industry, thus strengthening the regional economy. Therefore, it appears that the region's economy could be strengthened and the decline of oil and gas production greatly slowed by a policy to hold output constant through price.

It is also important to compare cumulative oil and gas production under the rapid, forecasted decline and the slowed, policy controlled decline. A total of 1.03 billion barrels of oil production is forecasted and exhaustion is reached in 2005, but with output constant the total is only 0.621 billion barrels by 2020. Gas is exhausted in 1997 in the original forecast at 14,400 million cubic feet but extends to 31,015 million cubic feet by 2020 in the simulation. The upper bound of the forecasted range is 24,933 million cubic feet of cumulative production by 2000. If it is believed that the 24,933 million cubic feet represents the physical limitation to production of gas then constant-output production would stop in 2012, a 15 year extension. However, to a large degree economic factors determine the amount of

Figure 4. Oil Prices: O_1, Forecast Price Path; O_2, 1978 Constant-Output Path; O_3, DOE World Crude Oil Price Path.

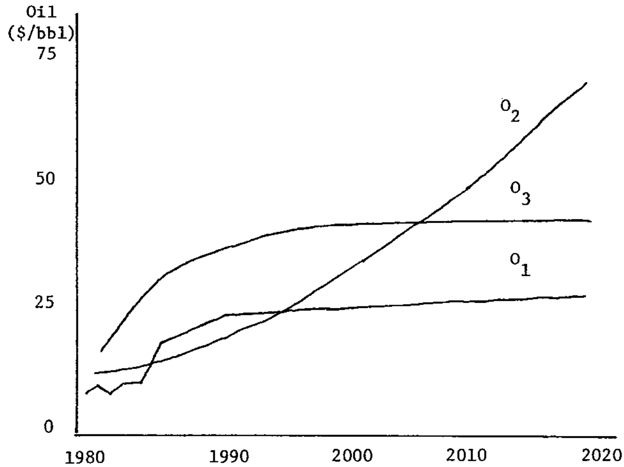
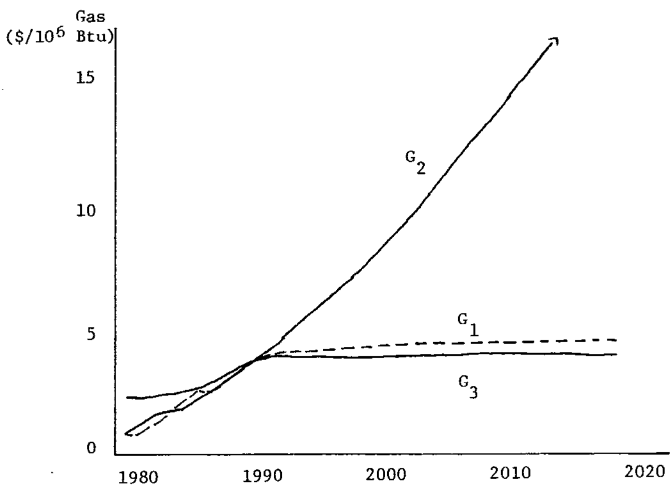


Figure 5. Gas Prices: G_1, Forecast Price Path; G_2, 1978 Constant-Output Path; G_3, DOE Domestic Average Wellhead Path.



recoverable reserves, so it is reasonable to expect a significant extension beyond the upper bound limit because the simulated price is increasing rapidly after 2000.

Summary and Conclusions

In the High Plains-Ogallala Aquifer area of Oklahoma, an agriculture and petroleum production region, prosperity is highly dependent on depletable resources — water and petroleum. This study forecasted some of the changes in the region based on the depletion of petroleum resources. It was found that decline and depletion of oil and gas production is likely before 2020. This most certainly will occur unless oil or gas is discovered at depths below the level of present technological experience. Of course, even such advances will not stop eventual decline, only delay it.

Petroleum production started in the area in the late 1940's and grew through the 1950's and 1960's. During the 1970's production declined and it is forecast in this study it will grow again in the 1980's and decline from the 1990's through the 2010's. During this three quarters of a century employment and income in the area will experience similar trends. However, it is during the transition decades of the 70's and 80's that the impact is first noticed because constant growth in employment and income — general prosperity — no longer exists. It is during this period that the fact of eventual decline becomes established and it is realized that mitigating adjustments need to be taken before decline starts, not before depletion happens.

Policies which may mitigate prosperity decline and general area hardship include mobility of labor, general funding of social overhead capital, general aid to the area, and tax/price incentives. The last policy was studied by simulating the price path which will keep oil and gas production equal to 1978 levels. It was found that this requires a policy which will keep prices below expected near term levels and allow a continuing smooth increase. That is, current and expected price will act to hasten decline of production. A tax to reduce prices in the near term will stave off decline and keep area prosperity constant or increasing as measured by direct employment and income associated with the oil and gas industry.

Appendix A: Definition of Variables

Dependent Variables	Definition
TOTOIL	Total production of crude petroleum measured in barrels unless otherwise noted.
TOTGAS	Total production of natural gas measured in MCF unless otherwise noted. Includes casinghead gas (MCF = thousand cubic feet)

Independent Variables	Definition
T	Time; 1950 = 1 to 1978 = 29.
T^2	Time squared.
Depth	Reported depths of fields and leases (feet).
R2OIL	Petroleum production lagged two years (barrels).
POILI5	Price of petroleum indexed to 1977, lagged five years ($/barrels).
T (gas model only)	Time; 1956 = 7 to 1978 = 29
PGASI2	Price of gas in BTU units, indexed to 1977, lagged one year ($/million btu).
R3GAS	Gas production lagged three years (MCF).

Appendix B

In association with production of oil and natural gas is the area employment and income resulting directly from this economic activity. The following relationships were estimated to relate oil and gas output level to employment and income. Employment in oil and gas production,

$$EOG = 398.9 + 3.679VOG,$$
$$R^2 = .75,\ N = 28$$

where VOG is the value of oil and gas from 1950 to 1978 in millions of 1977 dollars. Forecasted employment (EOG) is shown in Figure 3 labeled as E. This is direct employment only and does not include employment in well servicing, trucking, pipeline operations, or refining. The indirect employment would add about 28 percent to the direct level.

Income resulting directly from oil and gas production is comprised of wages and salary payments, royalty payments, and lease reservations payments. Wage and salary rates were estimated as a function of time over the 1950-1978 period in 1977 dollars,

$$OGY = -2E6 + 1002T,$$
$$R^2 = .81,\ N = 28,$$

where OGY is annual average wages and salaries. Annual wage and salary income is given by

$$OGI = OGY^{*}EOG.$$

Royalty payments are simply a fraction of the value of oil and gas production adjusted by the proportion which is paid nonresidents of the region. The fraction was ⅛ through 1975 and became 3/16 thereafter. During the whole period approximately ½ the total royalties accrued to nonresidents. These figures are based on records of the production companies and state tax statistics. Royalty payments are given by

$$RP = 0.50^{*}a_t^{*}VOG,$$

where RP is annual royalty payments in 1977 dollars and a_t is the fraction applicable each year.

Leasehold reservation payments are annual payments to landowners per acre leased or released each year. It was found that the acres leased each year (A) is a function of the successful wells (SWEL) completed during the previous year,

$$A = 261 + .693SWEL,$$
$$R^2 = .74,\ N = 10.$$

Annual leasehold reservation payments to area residents are then given by

$$LRP = 0.50^{*}b_t^{*}A,$$

where 0.50 is the proportion paid to residents of the area and b_t is the average per acre payment which increased from \$50-175 over the period 1969-1978.

Income directly resulting from oil and gas production is given by

$$I = OGI + RP + LRP,$$

and the forecast is shown in Figure 3. The proportions are typically 29 percent OGI, 31 percent LRP, and 40 percent RP during years of constant or increasing production and prices.

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