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TAX REVENUE AND INNOVATIONS IN NATURAL GAS SUPPLY: NEW MEXICO

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Our paper develops an econometric model of natural gas supply at the state-level using New Mexico as a case study. The supply model is estimated using annual time series observations on production levels, delivered prices, proved reserves, existing wells, and extraction costs. We validate the model against historical data and then use it to consider the fiscal impacts on state tax revenue from innovations in extraction technologies.

1. Introduction

Numerous authors have applied U.S. time series data in examining the empirical relevance of Harold Hotelling's theory of exhaustible resource production. The empirical findings reported in this literature support the notion that discoveries of new deposits, shifts in market structure, and changes in tax policy are relevant arguments in the supply of natural gas at the national level. Our immediate objective is to investigate the empirical relevance of these arguments in forecasting natural gas supply at the state-level using New Mexico as a case study.

We assume the supply of an exhaustible natural resource (Q) depends on two basic arguments: the price level of the resource (P) and the size of recoverable deposits (R), that is

$$Q = Q(R, P). \tag{1}$$

The importance of the second argument stems from the notion that reductions in extraction costs, e.g., average cost per well, may increase the size of recoverable reserves. Thus, we argue recoverable reserves depend inversely on recovery costs (C):

$$R = R(C) \quad \text{where} \quad \frac{dR}{dC} < 0. \tag{2}$$

Accordingly, the maintained hypotheses of our gas production model are twofold: natural gas supply increases relative to its price, and decreases relative to its recovery costs, i.e.,

$$\frac{dQ}{dP} > 0 \quad \text{and} \quad \frac{dQ}{dC} = \frac{\partial Q}{\partial R}\frac{dR}{dC} < 0. \tag{3}$$

The remainder of the paper develops and evaluates an econometric model of natural gas supply at the state-level taking these two basic arguments into account.

Referring to Figure 1, we measure natural gas supply in New Mexico using annual observations of marketed production levels between 1960-1992. As noted above, the amount of reserves available for extraction during these years is assumed to be inversely related to extraction costs as measured by average costs per well. Based on these specifications we consider the fiscal impacts of innovations in natural gas recovery, with the price level as an independent regressor variable. Overall, our empirical results agree with these model specifications according to our validation criteria. This encompasses goodness-of-fit, the expected signs of the parameter estimates, and ex-post forecasting performance. Section 2 describes the econometric model in greater detail, along with the data that was used in the estimation. Our empirical findings are reported in Section 3 along with the procedures used to estimate and validate the model. Finally, Section 4 summarizes the implications of supply innovations relative to tax revenue.

2. Model Specifications

From an econometric standpoint, natural gas production can be modelled as a function of price, proved reserves, existing recovery wells, and extraction costs. Proved reserves are defined as the quantity of natural gas "which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years under existing economic and operating conditions." Put more simply, proved reserves reflect the amount of known deposits that can be produced from wells in place at a particular date. Referring to Figures 2-5, annual time series observations on proved reserves (R), existing wells (W), average cost per well (C/W), and reserves per well (R/W) are readily available over the period (1960-1992).

As shown in Figure 5, New Mexico's reserves per well ratio declined throughout the 1960s and 1970s. Only in the mid-1980s did the ratio begin to increase for the first time. Looking ahead, this ratio may continue to increase as a result of "supply innovations" in resource recovery, i.e., events which reduce extraction costs across existing wells, thereby increasing the stock of economically recoverable reserves. Certainly the discovery of new deposits may do this, but so can research and development of new extraction processes which increase profit margins of existing wells. Here we will use the term "supply innovations" rather liberally, given that this can refer to a fairly wide range of behavior under varying assumptions of price, technology, and recovery efficiency.

Turning to the price term in expression (1), we assume the delivered price of natural gas reflects the state-of-the-market at the point of consumption. This raised the immediate question: which delivered price to use as an argument in the production decision. Recognizing that New Mexico's interstate sales have mostly gone to California, we constructed a weighted price series of a segmented market composed of New Mexico and California. See Figure 6. This time series is specified in units of real dollars per million cubic feet (mcf). Ultimately, this variable came to be specified as a lagged price ratio.

We also assumed that neither the rate of production or the amount of proved reserves caused the price changes shown in Figure 6. This assumption can be argued on grounds of price-taking behavior. However, the existence of regulated-pricing at the wellhead throughout the sample period provides a political motive for why prices would remain invariant to changes in either the stock of proved reserves or the level of production from existing wells. On the whole, our model specifications attempt to reflect a dynamic relationship between production, reserves, and the delivered price of natural gas across a segmented market.

3. Model Estimation

In the process of developing our econometric model, two objectives were of special interest: formulating a tractable model that is consistent with the theory of natural resource extraction, and using the empirical model to forecast the fiscal impacts of gas-recovery innovations. Consistent with these objectives, our econometric model exhibits a unilateral cause-and-effect relationship, whereby reserves per well are treated as a predetermined variable insofar as natural gas production is concerned.

To estimate the model, all of the variables were defined as natural logarithms making the model log-linear in the parameters. Moreover, the regressor variables defining reserves per well, cost per well, price, and production were all lagged in the final estimation of the model. Finally, we assumed the disturbance terms in the two-equation model remained serially uncorrelated throughout the sample period, thereby enabling us to apply ordinary least-squares (OLS) in the estimation of the model parameters. The OLS regression results are reported below.

$$R/W = \underset{(4.76)}{5.37} + \underset{(2.77)}{0.41}(R/W)_{-1} + \underset{(2.49)}{0.31}(R/W)_{-2} - \underset{(-4.78)}{-0.42}(C/W)_{-1} \qquad R^2=.95 \quad D.W.=2.67 \qquad \textbf{(4)}$$

$$Q = \underset{(1.23)}{1.67} + \underset{(2.51)}{0.01}T + \underset{(13.37)}{0.90}Q_{-1} + \underset{(2.31)}{0.56}(P_{-1}/P_{-2}) + \underset{(3.24)}{0.22}(R/W)_{-1} \qquad R^2=.85 \quad D.W.=2.16 \qquad \textbf{(5)}$$

We first examined the statistical aptness of the two-equation model by plotting the residuals of each equation against the predicted values and independent regressor variables. These plots are shown in Figures 7-12. There are no suggestions in any of these plots that systematic deviations from the fitted regression plane are present, nor that the error variances are sensitive to either the level of the fitted values, or the levels of the independent regressors. Overall, the two-equation model appears to fit the data reasonably well, as indicated by the adjusted R-squared values (.95 and .85). Meanwhile, the signs of the parameter estimates correspond to the maintained hypothesis of the model.

Referring to their respective t-values (shown in parenthesis), these estimates are statistically significant at the 90 percent level of confidence. Intuitively, expression (4) suggests decreases in the average costs per well will increase the level of reserves per well, while expression (5) suggests that increases in either price or reserves per well will increase the rate of natural gas production. These empirical findings are in accord with the maintained hypothesis of the model. The final step of our analysis uses the structural model to consider what impacts supply innovations might have on gas production and tax revenue.

4. Policy Implications

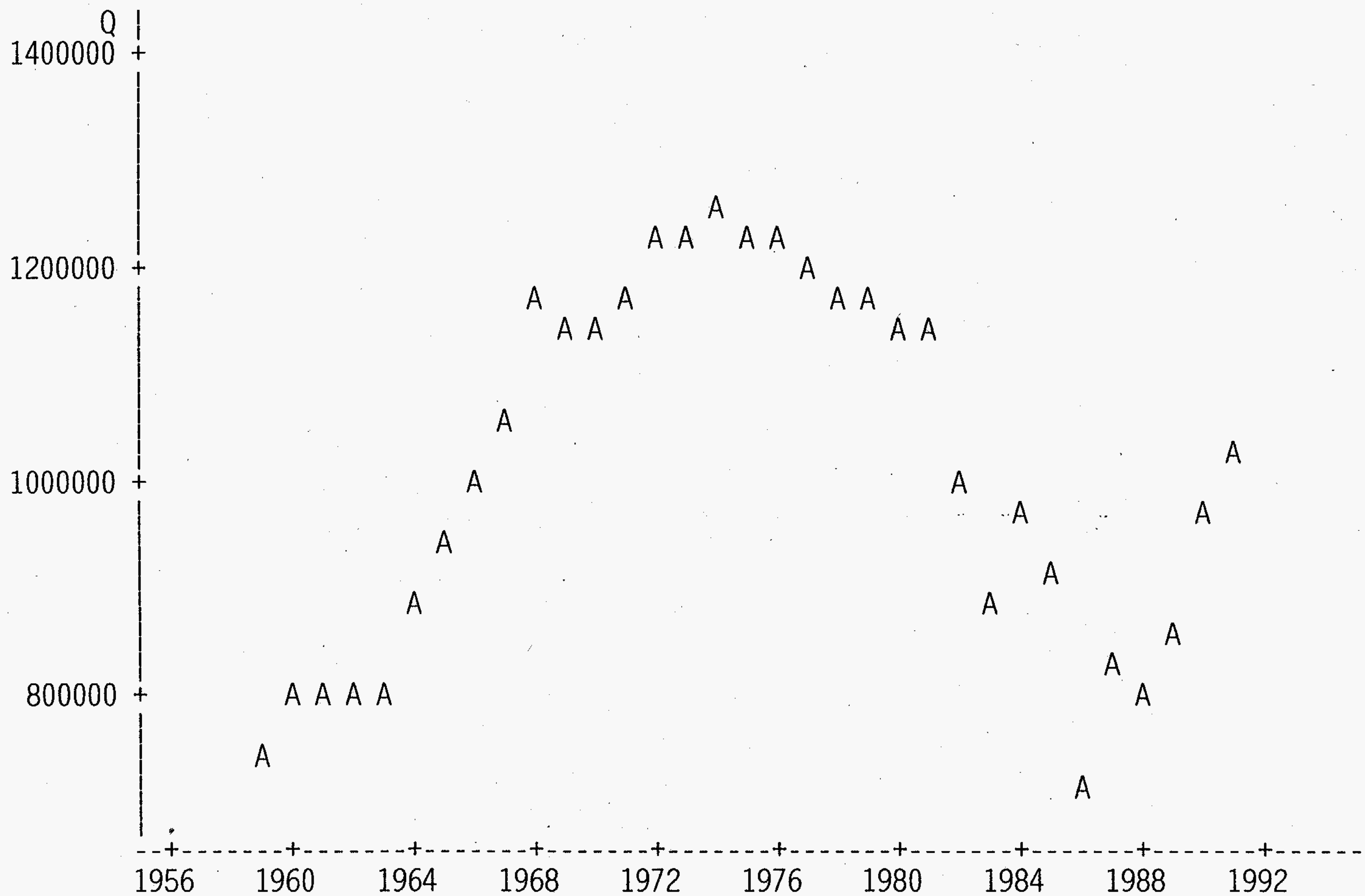
Presently, the effective tax rate on natural gas extraction in the State of New Mexico is .1353 per thousand cubic feet (tcf), and is a composite of 5 different tax rates: the state school tax, an oil and gas severance tax, a conservation tax, an ad valorem production tax, and a tax on production equipment ad valorem. For present purposes we use the composite unit tax rate of .1353 provided by the New Mexico Department of Finance to consider the sensitivity of state tax revenue to supply innovations.

As a benchmark, we forecast production to be 1,424 billion cubic feet (bcf) in 1994 using an average real cost of $385,000 per well. This forecast is based on 1993 reserves of 20.4 trillion cubic feet and 20,274 active wells. Using these values our 1994 forecast appears to be quite realistic; only 3.2 percent below the official state forecast for fiscal year 1994, i.e., 1,471 bcf. Assuming technological innovations in extraction induce cost-savings, we went on to consider two other supply scenarios: what if average costs declined to $300,000 and $225,000 per well? Here we have estimated that supply would increase by 33.2 bcf under the former, and by 72.5 bcf under the latter. Note that the predicted change of 72.5/bcf is consistent with a 40 percent reduction in the real costs per well of 1991. This scenario is also consistent with the national cost trends observed in Figure 4.

This brings us to the policy question of the paper: what impacts would cost-saving technological innovation have on state tax revenue? Note that an effective unit tax rate of .1353/tcf is equivalent to $135,000/bcf. Therefore, under our prediction that 40 percent real cost-savings increases New Mexico gas supply by 72.5/bcf per year, we estimate that the tax revenue from gas production would increase by approximately $10 million in 1994 dollars. This estimate is conservative given the implicit assumption that natural gas prices would remain relatively constant. The alternative is to assume that the demand for New Mexico natural gas causes either a coincidental increase (or decrease) in natural gas prices which would either increase (or decrease) the fiscal impacts of technological innovations.

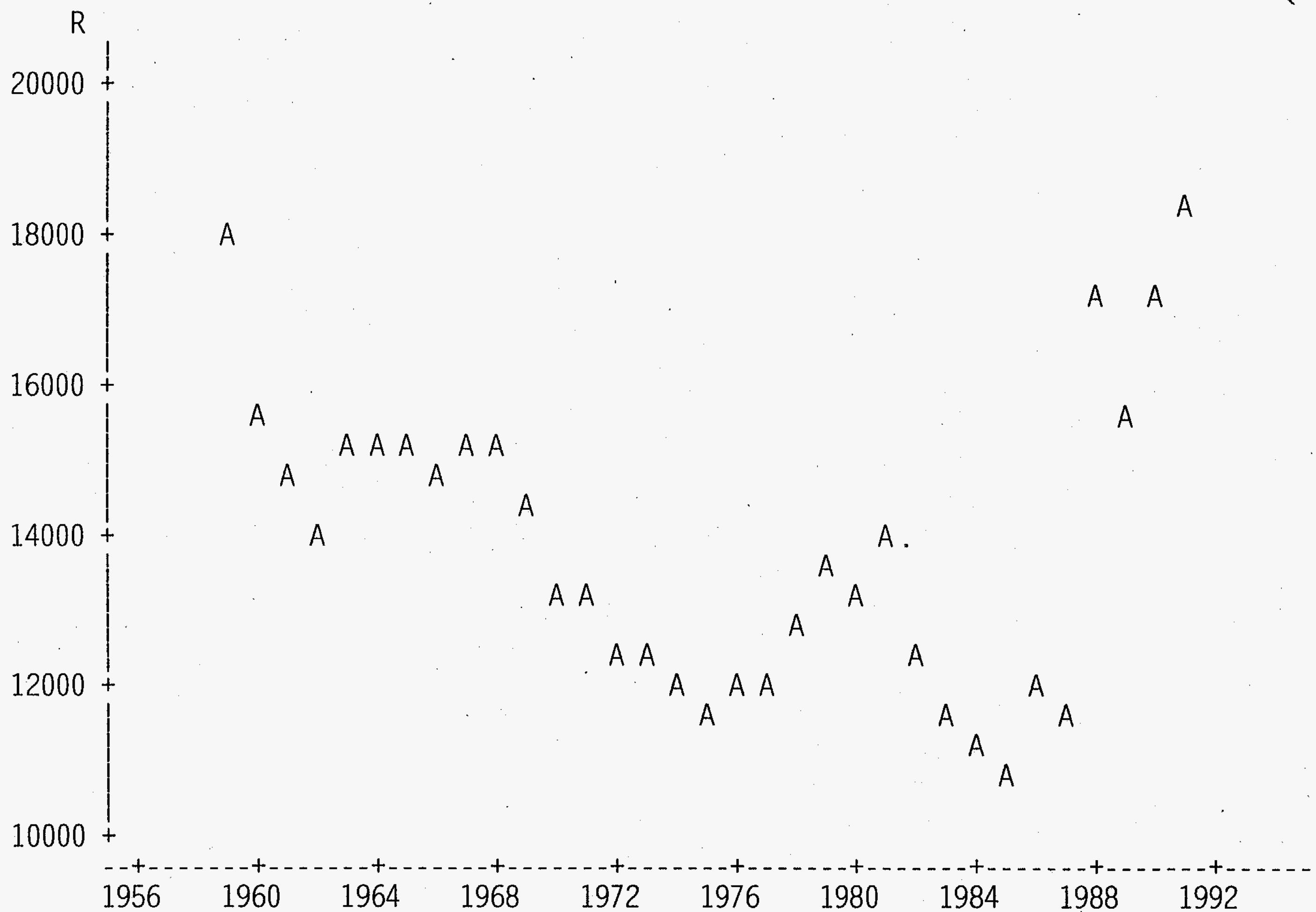
In summary we suggest that New Mexico residents would experience some benefits from the introduction of innovative technologies in the production of natural gas. Indeed, a public annuity of $10 million from 40 percent cost-savings would be enough to buy every Albuquerque resident one $20 dinner once per year! Thus we would argue that tax policies aimed at encouraging the use of innovative extraction technologies would tend to have positive impacts on the amount of tax revenue collected from the production of natural gas.

FIGURE 1: PRODUCTION OF NATURAL GAS IN NM (mcf)



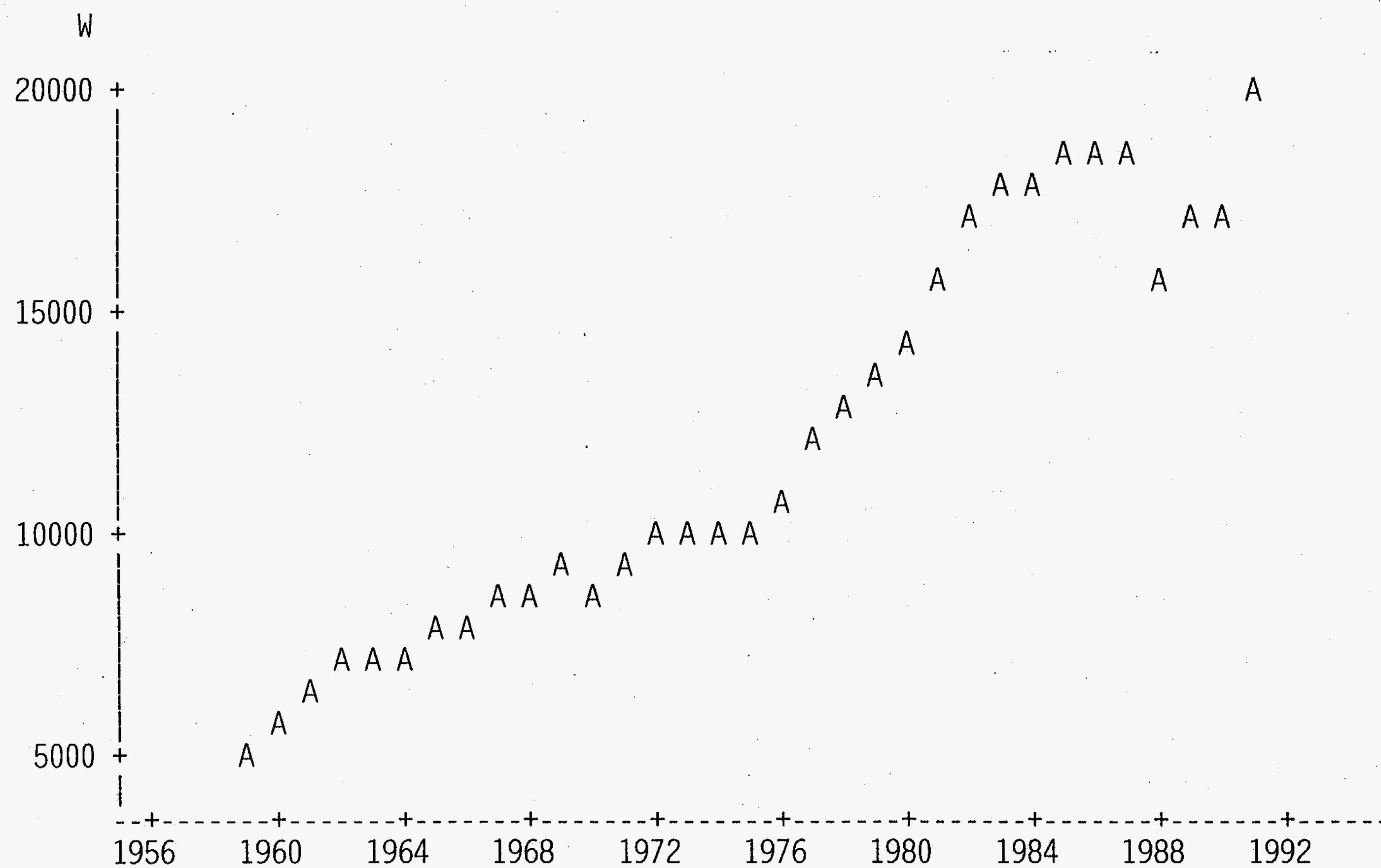
Sources: 1947-1975 U.S. Bureau of Mines, Natural Gas Annuals;
1976-1991 U.S. Energy Information Administration, Natural Gas Annuals.

FIGURE 2: PROVED RESERVES OF NATURAL GAS IN NM (bcf)



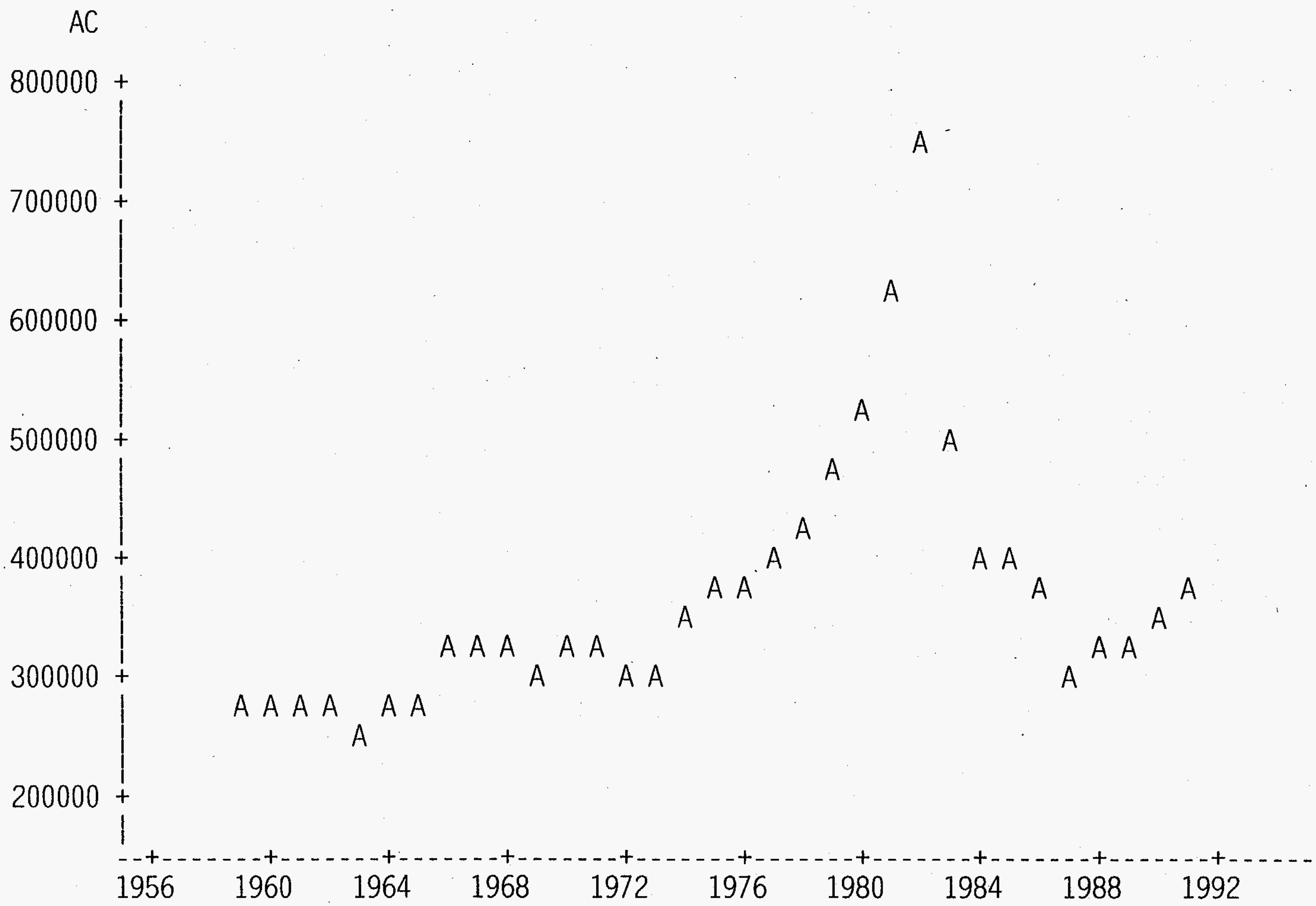
Sources: 1947-1976 American Petroleum Institute, American Gas Association, Reserves of Natural Gas in the U.S. Annuals; 1977-1991 U.S. Energy Information Administration Natural Gas Annuals.

FIGURE 3: PRODUCING NATURAL GAS AND CONDENSATE WELLS IN NM



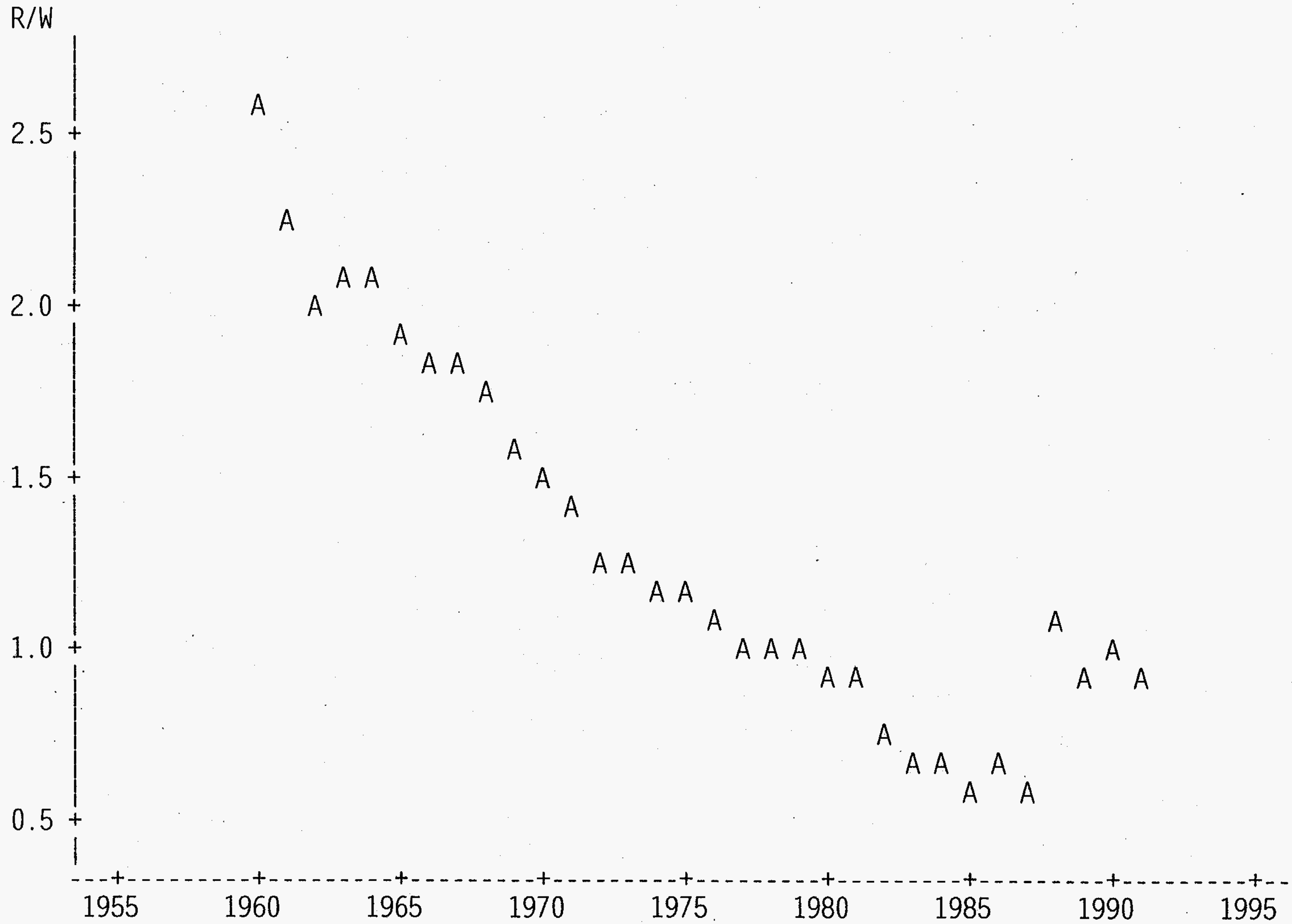
Sources: 1947-1980 U.S. Bureau of Mines, Natural Gas Annuals;
1981-1991 U.S. Energy Information Administration, Natural Gas Annuals.

FIGURE 4: ESTIMATED AVERAGE REAL COST PER WELL
(Onshore U.S. Gas Wells)



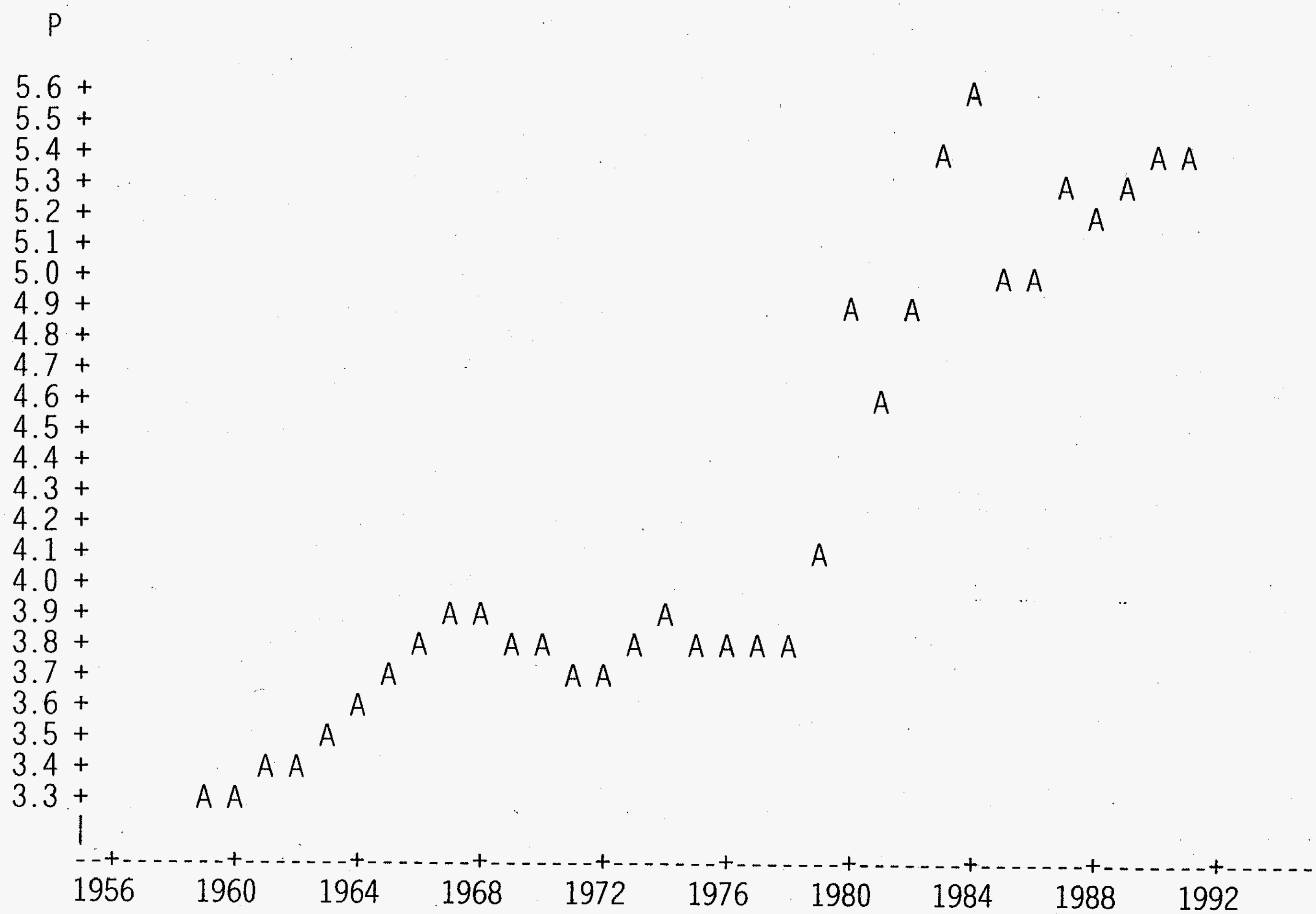
Source: American Petroleum Institute, Joint Association on Drilling Costs, Annual.

FIGURE 5: NM PROVED RESERVES PER WELL



Sources: see figures 1 and 2.

FIGURE 6: WEIGHTED DELIVERED REAL PRICE OF NATURAL GAS (NM and CA per tcf)



Sources: U.S. Energy Information Administration, Natural Gas Annuals; Consumer Price Index for piped natural gas.