TECHNICAL INEFFICIENCY AND PRODUCTIVE DECLINE IN THE U.S. INTERSTATE NATURAL GAS PIPELINE INDUSTRY UNDER THE NATURAL GAS POLICY ACT

by

Robin C. Sickles
and
Mary L. Streitwieser

R.R. #89-20

April 1989

TECHNICAL INEFFICIENCY AND PRODUCTIVE DECLINE IN THE U.S. INTERSTATE NATURAL GAS PIPELINE INDUSTRY UNDER THE NATURAL GAS POLICY ACT

Robin C. Sickles and Mary L. Streitwieser

Rice University
P.O. Box 1892
Houston, Texas 77251

Revised
April 1989

The authors would like to thank William A. Johnson for his helpful comments and suggestions. They also gratefully acknowledge support from the C.V. Starr Center for Applied Economics.

ABSTRACT

TECHNICAL INEFFICIENCY AND PRODUCTIVE DECLINE IN THE U.S. INTERSTATE NATURAL GAS PIPELINE INDUSTRY UNDER THE NATURAL GAS POLICY ACT

The purpose of this paper is to examine the primal production technology of the interstate natural gas pipeline industry during a period (1977-85) in which the industry faced severe changes in the regulatory environment. We utilize a newly constructed panel data set of firms that comprise almost 90% of the industry. We find that during the first six years of partial price deregulation, there was a marked decline in productivity. The only firms which maintained positive productivity rates were those with relatively large and growing transport services for others. We also find that firm-specific average efficiency rankings were strongly and negatively correlated with firm size. We conjecture that this may be due to the rate base regulation in the industry and the relative ease with which larger firms can pad their base and produce at levels that are inconsistent with frontier levels of production.

I. Introduction

The U.S. natural gas industry has undergoing substantial change in the past decade. The enactment of the Natural Gas Policy Act of 1978 (NGPA)[1] set initial ceiling well-head prices and escalation schedules for over two dozen categories of natural gas.[2] Approximately 55 to 60 percent of flowing natural gas was released from field price control by January 1985. As a result, this industry is experiencing serious price competition, both from within the industry and from alternative fuels (residual fuel oil, nuclear, and coal) for the first time. Simultaneously, demand has declined due to general energy conservation and the disappearance of traditional industrial users. The new inter-fuel competition is largely a result of the change in regulation of natural gas field prices,[3] recently declining oil prices,[4] and technological innovation of multi-fuel boilers used by utility companies and industry. This study covers the transition period 1977-85.

---

[1] Natural Gas Policy Act of 1978, U.S. code, Supp. 5, Title 15.

[2] Natural Gas is classified according to well vintage, commitment to intra- or interstate markets, type of geological formation, rate of production, and the provision of existing gas sale contracts. For a summary of the NGPA gas categories and their respective pricing regulation see The Natural Gas Regulation Handbook, Pierce (1980).

[3] Intrastate pipeline companies are not subject to federal rate of return regulation. However, the deregulation of well-head gas prices covered in the Natural Gas Policy Act does apply to purchases by both inter- and intrastate pipeline companies. In most other respects, intrastate companies are regulated at the state level.

[4] U.S. crude oil price control was ended in 1981. This, coupled with declining demand and the weaking of OPEC to control output lead to a steady drop in crude oil prices.

Supporters of the partial deregulation argued that the new regulatory environment would allow the price of gas to reflect market conditions and enhance competition and efficiency in the industry. The industry's adjustment to the change in regulation has been more disruptive than anticipated and whether efficiency has been improved or not has not yet been analyzed. The pressures of rising average price and falling demand have placed considerable stress on the institutions of the natural gas industry and the traditional transactional arrangements.

We are aware of no other empirical studies of the impact of the NGPA on the natural gas transmission industry. The purpose of this paper is threefold. The first is to analyze the production structure of the interstate pipeline industry under the NGPA, based on a newly constructed panel of twenty-four firms. Particular attention is focused on the pattern of substitution among the factor inputs and the degree to which the production function is characterized by economies of scale. Second, the components of productive growth and decline during the years 1977-1985 are examined and compared to an earlier study by Aivazian, et al. (1987). Their paper addressed the role of economies of scale and productive growth in the industry prior to deregulation efforts. Finally, we examine differences in technical efficiency among firms.

We chose to estimate a production function for several reasons. First, the technology of the natural gas transmission industry is relative simple: natural gas is transported a distance through pressurized pipelines, with or without the firm also acting as gas merchant. Second, the estimated scale economy factor can be tested against an upper bound of 2.07 derived from laboratory experiments for natural gas pipelines (Robinson, 1972).[5] The available data permits the measurement of inputs and output in physical units and isolates the expenses associated with transmission activities from those incurred in production, distribution, storage, and administrative activities. Finally, we will be able to compare our results with those of Aivazian, et al. (1987), who analyzed the transmission industry during its growth years, 1953-79.

The econometric production model of natural gas technology are described in Section II. Section III describes the data base. The results and concluding remarks are contained in Sections IV and V respectively. A more detailed description of the data and their sources is contained in the Appendix.

II. The Model

We use a translog production function,[6] specifying a homothetic technology in which a time index measures technical change.[7] Dummy variables are used to represent three different regulatory epochs: one for the years before the NGPA went into effect (1977-78), a second for the years after the NGPA was

---

[5] Other economic studies which have relied on Robinson's results include Callen (1978), Aivazian and Callen (1981), and Aivazian, et al. (1987).

[6] Earlier studies, Chenery (1949), Cookenboo (1952), and Callen (1978), employed Cobb-Douglas forms.

[7] See, for example, Gollop and Jorgenson (1980), Jorgenson and Fraumeni (1981), and Gollop and Roberts (1983).

passed, but before FERC Order 436[8] (1979-84), and a third for 1985 when FERC Order 436 was effective and the development of the natural gas spot market. We also allow for firm effects in production. These effects can also be interpreted as average firm inefficiencies over the sample period (Schmidt and Sickles, 1984). The model takes the form:

$$\begin{aligned} \ln Y_{it} &= \beta_o + \Theta(\Sigma\alpha_i \ln X_{it} + \tfrac{1}{2}\Sigma\Sigma\alpha_{ij}\ln X_{it}\ln X_{jt} + \Sigma\delta_{ti}\ln x_{it}T) + \\ &\quad \delta_t T + \tfrac{1}{2}\delta_{tt}T^2 + \Sigma\gamma_k EPOCH_k + v_{it} - u_i \qquad (1) \\ &= \beta_o + [\cdot]_{it} + v_{it} - u_i, \\ i &= 1,\dots,N,\ t = 1,\dots,T. \end{aligned}$$

Several restrictions are imposed on the estimated parameters to insure homogeneity and symmetry. These restrictions are:

$$\Sigma\alpha_i = 1,$$

$$\Sigma\alpha_{ij} = 0, \qquad j = 1,2,3,4,$$

$$\alpha_{ij} = \alpha_{ji} \qquad \forall\ i,j.$$

If we interpret the firm effects as average firm inefficiencies over the sample period, then the u_i represent technical inefficiency and correspondingly, $u_i \geq 0$ for all i. The u_i are assumed to be iid with mean μ and variance $\sigma^2{}_u$ and to be independent of the v_{it}. The production function's constant term and composed error structure can be reparameterized as

$$\ln Y_{it} = \beta_i + [\cdot]_{it} + v_{it}$$

where $\beta_i = \beta_o - u_i$. For any fixed Θ, the variables in brackets would simply be rescaled and a conditional within transformation

---

[8] FERC Order 436 allows for voluntary, non-discriminatory open transport by pipelines as carriers, rather than as merchants and carriers. Few pipelines have received and accepted an Order 436 ruling; most still operate under Section 311 of NGPA.

could be performed. Alternatively, one could use dummy variables. The advantage of dummy variables (or the conditional within estimator) is that its consistency does not require the regressors to be uncorrelated with the effects. Furthermore, we can use the fact the $u_i \geq 0$ to normalize the effects (u_i) and the constant term β_o. Let the N estimated intercepts be $\hat{\beta}_1,\ldots,\hat{\beta}_n$, and define

$$\hat{\beta}_o = \max(\hat{\beta}_i) \text{ and } \hat{u}_i = \hat{\beta}_0 - \hat{\beta}_i, \qquad i = 1,\ldots,N.$$

Then the most efficient firm in the sample is normalized to be 100 percent efficient, and given the functional form for the production function, these renormalized firm effects can be interpreted directly as relative efficiency levels (%).

Our use of dummy variables (the within estimator) means that the Zellner, Kmenta, and Dreze (1966) argument, that error in stochastic production functions represent events beyond the control of the firm, requires some modification. We assume here that the uncorrelatedness applies between the (possibly) endogeneous input levels and the error term v_{it}. Although a substantial amount of unexplained variation has been removed by the dummy variables estimator, we also control for nonsystematic firm specific effects that may contaminate the error structure by positing a firm-specific vector autoregressive structure of the form $v_{it} = \rho_i v_{i,t-1} + \xi_{it}$ where the ξ_{it} are assumed to be identically and independently distributed with zero mean and variance σ_ξ^2.

Given exogeneous input prices w_i, and utilizing Shephard's Lemma and Euler's Theorem, first-order conditions describing the production of expected output at minimum costs are expressed in share form as

$$S_{it} = \alpha_i + \sum_j \alpha_{ij} \ln X_j + \delta_i T + \varepsilon_{it}, \qquad i = 1,\ldots,4, \qquad (2)$$

where additive disturbances, ε_{it} have been appended to each share equation and represent unobserved and nonsystematic allocative inefficiencies. The vector of share equation errors is assumed to be independently and identically distributed with zero mean and covariance Σ_ε, and to be correlated with ξ_{it}. The system (1) and n-1 of the cost share equations (2) are estimated by iterative nonlinear seemingly unrelated regressions, using the suitably modified system covariance structure outlined above. In Section IV we examine the potential for correlation among the inputs and the random errors using the Hausman-Wu test. For fixed Θ, our generalized nonlinear instrumental variables estimator (which is consistent under the null hypothesis of no correlation as well as the alternative hypothesis of nonzero correlation) becomes a special case of the generalized method of moments estimator considered by Schmidt and Wyhowski (1988) for simultaneous equations models which use panel data.

We assume the industry is cost minimizing[9] due to market forces, not necessarily FERC (Federal Energy Regulatory Commission) oversight. Using the production function implicitly assumes that input prices are set in competitive markets and not influenced by firm behavior. No assumption is made about output price.

---

[9] Some might argue that, given the excess capacity of the industry, firms behave as output maximizers (see Fanara, Jr. and Sweet, 1982), seeking to increase their transports for others as much as possible. Filling excess capacity is undoubtably a consideration; however, we assume the market pressures to be competitive, and thus cost minimizing, is dominant.

Labor prices are competitively set; there are no unions involved in negotiating labor contracts. The only potential problem is the price of energy. Under the NGPA, the natural gas used by the firm may be decontrolled, in which case the price is set by the market; however, it could be gas that is still under price control (i.e. its vintage cost price), or a mix of the two. In any case, the price of energy to the firm is exogenously set, either by the market or by Federal price control, and the firm has no influence over the price.

Even though input prices appear exogenous, whether or not the transmission industry is a cost minimizer has been subject to some debate, due to the "cost-plus" nature of its regulation. One type of transmission activity, sale for resale, is regulated by FERC. Simply stated, a price schedule for these sales is established by FERC such that the firm recoups its operating costs and a fair rate of return on its capital investment. It has been argued that given this type of regulation the firm will select a non-optimal input mix, specifically, over-capitalize (the Averch-Johnson effect). In addition, because it recoups its operating and maintenance costs, it simply has no incentive to cost minimize.

We contend that the industry does have the incentive to cost minimize. Regulators do scrutinize the costs of the firms during the rate hearings. Costs are required to be well documented and reasonable. FERC has been known to disallow some expenses. Furthermore, the rate regulation does not guarantee that the firm will earn the allowed rate of return; it merely makes it possible.

In actuality, any shortfall or excess profit earned is considered a windfall loss or gain. Thus, once the rate structure is set, the firm has every reason to minimize costs in order to maximize its return. In the past, regulatory lag generally benefited the firm. Presently the opposite is more accurate, since firms cannot quickly adjust their rates to reflect increasing costs and declining throughput. Thus the regulatory process can impose some discipline on the pipelines' costs, particularly as the regulatory lag has been increasing over time.[10] Lacking conclusive evidence to support or refute either argument,[11] we assume the industry seeks to minimize costs.

III. The Data

The technology of the natural gas pipeline industry is fairly straightforward. The firm acts as a merchant and/or carrier of natural gas. As a merchant it buys natural gas from the producing fields, compresses and transports it through long distance pipelines, and resells the gas at the point of delivery to local distributors (sales for resale) or industrial

---

[10] Stich and Smith found that the time required to process rate cases increased from 405 days in 1973 to 697 days in 1979. Between 1980 and 1982 the time requirement has fluctuated substantially.

[11] Callen (1978) found that in 1965, of the 28 firms studied, the majority employed too much pipeline capacity relative to compressor capacity to be consistent with cost minimization. However, he was unable to measure the relative input usage of energy or labor. He argues that the cost of input distortions is more than made up for by the benefits of regulation (increased output). Nelson and Wohar's (1983) study of the electric power industry indicates that the Averch-Johnson effect occured only during the 1970's, a period of instability due to rising average costs and active regulation.

users (mainline sales). The firm also transports gas for others without being a gas merchant.[12] The major factor inputs are the pipeline itself, compressor stations to regulate the flow of gas, energy to fuel the compressors (primarily natural gas), and labor.

Data are collected on twenty-four major[13] interstate natural gas pipeline companies for nine years, 1977-1985. All data are extracted from the firm specific FERC Form-2: Annual Report of Major Natural Gas Pipeline Company or the Annual Statistics of Interstate Natural Gas Pipeline Companies. Both are available from the Federal Energy Regulatory Commission.

Output and input quantities and prices are defined following the basic format of Aivazian, et al. (1987). Total output is measured by the total amount of gas delivered (in billion cubic feet) to local distribution companies, industrial customers, and gas transported for others multiplied by the distance (miles) transported.[14] The quantity of labor is calculated by determining the proportion of transmission labor expenses relative to total labor expenses. This ratio is multiplied by the total number of firm employees. The quantity of energy consumed in production is

---

[12] Transport for others is becoming an important activity for the transmission industry, increasing from 17.3 percent (1977) to 36.7 percent (1985) of the volume of gas transported by the firms in our sample. One company, Columbia Gulf Pipeline engages exclusively in transport for others.

[13] Major interstate natural gas pipeline companies are those which have combined gas sales for resale, transport, or storage (for a fee) that exceed 50 billion cubic feet/year. Thirty-three companies met this criteria in 1980.

[14] Aivazian, et al. did not include transport for other in their measurement of output. We have included it here because of its increasing importance to the industry.

measured by thousand cubic feet of natural gas used in transmission. Two measures of capital are used. Compressor station services are measured by the total horsepower rating of all compressors in place on the transmission lines. A measure of the tons of steel of transmission pipelines represents pipeline capital services. The quantity of pipeline capital is calculated as the miles of transmission lines multiplied by the square of the (weighted) average diameter and by the proportionality constant developed by Callen (1978).[15]

The price of labor and energy are derived by dividing total labor and energy expenses by their respective quantities. The user cost for capital services are estimated on a value added basis. Labor and energy expenses are netted out of total revenues from sales for resale, industrial sales, and transport of gas of others. Second, the cost of gas is subtracted out. The residual is allocated between compressor and pipeline services based on the ratio of book value and operating and maintenance costs of compressors to pipelines. The resulting residual attributed to compressors is divided by total horsepower to obtain the compressor user price. Similarly, the resulting residual attributed to pipelines is divided by the quantity of pipeline services to obtain the pipeline user price. All prices and quantities, other than output, are scaled such that the geometric mean equals zero. A more detailed description of the data sources and the construction of the variables is contained in the Appendix.

---

[15] See equation A8, page 320: $P = .382d^2L$ where P = pipeline capital services, d = weighted average diameter, and L = miles of transmission pipelines.

IV. Estimation Results

Five models are considered in our analysis. These models make alternative assumptions about firm efficiency differentials, technological structure, and scale economies. We impose no restrictions (other than the homogeneity restrictions) on Model I. Model II assumes there are no efficiency differentials among firms and Model III restricts the technology to be Cobb-Douglas. The restrictions of no technological change and constant returns to scale are imposed on Models IV and V respectively. Each of the restricted Models II through V was tested as the null hypothesis against the alternative unrestricted Model I. The calculated chi-square statistic from the Wald test is compared to the 95 percent critical chi-square distribution.[16] All models are rejected by the sample data, as reported in Table 1.

Estimates of the parameters for the unrestricted production function and share equations of Model I are presented in Table 2. The estimated Θ parameter indicates the technology exhibits increasing returns to scale ($\Theta = 1.9670$); this is consistent with other studies of the industry.[17] Monotonicity and quasi-concavity of the production function are tested by examining the estimated expenditure shares and the bordered Hessian matrix. Monotonicity requires the expenditure shares be non-negative. This condition

---

[16] The Wald test relies only on the unrestricted (Model I) estimates: $W = (\hat{\beta}_r - \bar{\beta}_r)[V(\hat{\beta}_r)](\hat{\beta}_r - \bar{\beta}_r)'$, where $V(\hat{\beta}_r)^{-1}$ is the covariance matrix of the maximum likelihood estimates of $\hat{\beta}_r$, and $\bar{\beta}_r$ are the restrictions being tested. W has an (asymptotically) chi-square distribution with r degrees of freedom.

[17] Aivazian, et al. estimated returns to scale at 1.9223 and Robinson's (1972) engineering based estimate is 2.07.

was met by 209 (97 percent) of the 216 observations in our sample. Convexity requires the bordered Hessian matrix be negative definite. This condition was met by the bordered Hessian matrix evaluated at the estimated sample means. The assumption of no correlation between the inputs and the error term (v_{it}) in the production function is tested via the Hausman-Wu test. At the 95 percent level, the test statistic is 3.08. The critical level for a chi-squared with 18 degrees of freedom is 28.87. We are unable to reject the null hypothesis of no correlation at this level of confidence.

Table 3 shows the price elasticities of demand.[18] The long-run own price elasticities are all of the correct sign; they represent fairly elastic responses to price changes, particularly for horsepower capital services. Long-run input substitutability appears to be moderate to high. Labor and compressors are complements, as are energy and pipeline capital.

Some of the more interesting results of our analysis deal with changes in productivity which have occurred since the NGPA was enacted, as well as with firm specific efficiency rankings.

---

[18] The Allen-Uzawa partial elasticities are normally calculated as $\sigma_{ij} = (\Sigma f_i x_i / x_i x_j)(F_{ij}/|F|)$, where $Y = f(L,E,H,P)c^{\theta}$, F_{ij} is the cofactor for element f_i in matrix F, $|F|$ is the determinant of F, and F is the bordered Hessian matrix. When using a log linear production function as we have, we calculate σ_{ij} as follows $\sigma_{ij} = G_{ij}/|G|$, where G is the matrix with the border elements equal to the estimated expense shares of the inputs (S_i), the diagonal elements are of the form $(\alpha_{ii} + \Theta S_i^2 - S_i)$, and the off-diagonal elements are of the form $(\alpha_{ij} + \Theta S_i S_j)$, Θ is the estimated returns to scale parameter and $_{ij}$ is the estimated parameter on the $\ln(X_i)\ln(X_j)$ variable, G_{ij} is the cofactor of element g_{ij} in matrix G, $|G|$ is the determinant of G. Price elasticities of demand are calculated as $n_i = S_i \sigma_{ii}$ and $n_{ij} = S_j \sigma_{ij}$.

Annual changes in total factor productivity, as well as the change in the average total productivity and for each factor are presented in Table 4.[19] Changes in productivity closely reflect changes in the level of output for our sample. With the NGPA in effect, productivity in the interstate natural gas pipeline industry has declined every year since 1979, except for 1984, which had an unusually cold winter. The 1982-83 and 1985 declines are dramatic: 8.2 percent, 7.5 percent, and 8.7 percent respectivity.

The 1982 and 1983 declines in productivity reflects the sharp decline in interstate natural gas throughput (7.9 percent and 12.6 percent) and the industry's inability to adjust inputs quickly. Two events contributed to the sharp decline in demand. First, the economic downturn in 1982 depressed the demand for natural gas by the industrial sector; a traditional market for the transmission industry. Second, all categories of consumers responded to the increasing gas prices by simply cutting back their consumption. The elasticity of demand for natural gas had been severely underestimated and excess capacity spread throughout the industry.

The small positive change (.3 percent) in productivity in

---

[19] The change in average total factor productivity is measured by the Tornqvist index, modified for scale economies:

$$T\dot{F}P = \dot{Y} - \Theta\Sigma 1/2(S_{it} + S_{it-1})\dot{X}_i,$$

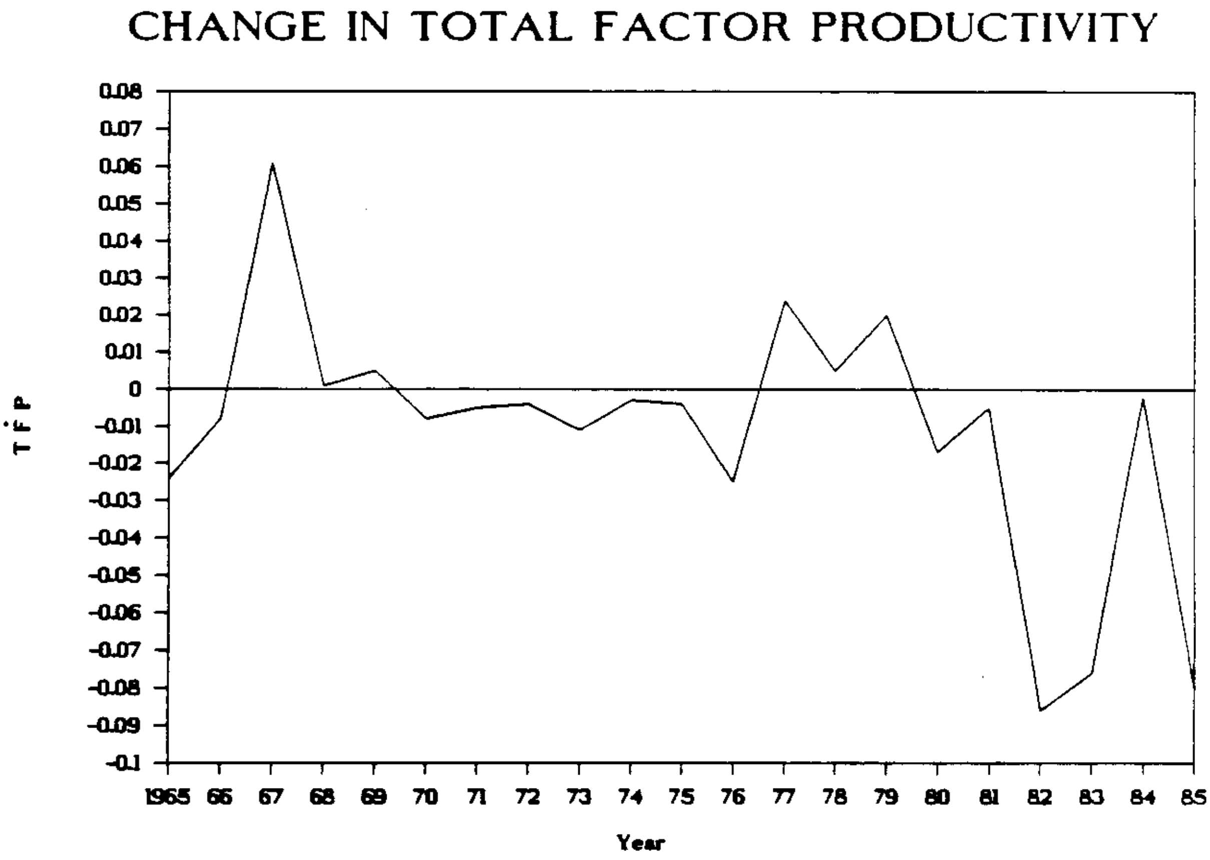
where $\dot{Y} = \ln(Y_t/Y_{t-1})$ and $\dot{X}_i = \ln(X_{it}/X_{it-1})$. The change in average productivity of factor X_i is measured by

$$A\dot{P}X_i = \Sigma S_j(\dot{X}_j - \dot{X}_i) + T\dot{F}P + (\Theta-1)\Sigma S_j\dot{X}_j.$$

1984 reflects the increase in overall energy demand, a response to the expansion of the economy in 1984 and a colder than usually winter. Throughout the early 1980's the pipeline companies began to feel the full force of previously made commitments to purchase high cost gas even in times of falling demand. There was now an excess supply of gas, which pipelines were contractually committed to buy at higher than market prices. The sharp 1985 decline in productivity occurred as the liability issue resulting from the contractual agreements to purchase more gas than needed at higher than market prices was reaching its culmination. Numerous court and FERC practice has allowed at least partial payments of these "take-or-pay" obligations. In addition, FERC continued its efforts to expand the pipelines' carrier role, with open access to all. This has had the effect of further decreasing the industry's traditional sales for resale and industrial sales.

Figure 1 shows the average change in total factor productivity over time. In addition to the measures derived from our post-NGPA sample, the historical changes in productivity were derived by using the Aivazian, et al. (1987) estimated model and our data for 1964-77. The partial deregulation years after 1977 are not the first period of declining productivity for the industry. Substantial declines also occurred from 1971-77, expect 1976. This was the period of falling natural gas supplies to the interstate market and the subsequent curtailment of (interstate) pipeline deliveries which precipitated the 1978 NGPA legislation.[20] Clearly, a decline in total factor productivity occurs when there is excess capacity in the industry. Such excess capacity can exist when the supply and throughput of gas falls in response to artificially low prices, as in 1971-77, or when demand declines in response to rapidly rising prices, as in 1980-85.

FIGURE 1



As Table 5 shows, the decline in total productivity occurred for all but four of the twenty-four firms studies. In general,

---

[20] Curtailments to industrial customers began in 1970 and continued through 1977, when curtailments of "firm" contracted gas deliveries reached 3.6 tcf.

the more productive firms are those with a (relatively) large, and growing portion of their throughput being transport for others. However, increasing transport for others services alone has not been a guarantee of increased productivity. The two firms which experienced the greatest productivity declines are those that usually transport large quantities of natural gas for other pipeline companies. In times of declining demand, purchases from other pipeline companies are usually the first to be cut.

It appears, on average, that the industry was able to make more efficient use of its own energy consumption, but was less efficient in its use of labor and capital. The decline in compressor (horsepower) and pipeline capital services is not surprising in a period of declining output, as these quantities cannot be easily altered. Labor is a quasi-fixed input as personnel are required to man and maintain the compressor stations and pipelines regardless of the proportion of capacity throughput being met.

Table 6 shows the rankings of estimated technical efficiency levels and average throughputs by firm for 1977-85. The relative efficiency levels are based on the dummy variable fixed effects efficiency estimates outlined in Section II. An absolute measure of technical efficiency is given by the expression $TE = (\hat{\beta}^{max} - \hat{\beta}_i)$. Results suggest that firm size is strongly negatively correlated with firm relative efficiencies. The Pearson correlation coefficient between the level of output and relative efficiency stands at -0.70 while the Spearman rank correlation is -0.79. Both estimates are significantly negative at the 99 percent level. This finding is consistent with evidence that the largest (and by our measures the least efficient) firms did not suffer production declines as large as declines of smaller firms in the industry during our sample period. It is plausible that, due to the rather large capital stocks of these larger companies, they are the most capable of padding their rate base, and in so doing, producing at inefficient levels. The substantial variation in the efficiency levels may be due in part to the sensitivity of the estimates to extreme observations since they are based on sample order statistics. Moreover, the firm effects may be picking up not only slackness in management practices and FERC regulatory oversight, but also sluggish adjustments of capital inputs and declining demand. We are also estimating average efficiency levels within a firm over the sample period. If there are substantial variations in efficiencies over the sample period then comparisons of averages may be somewhat misleading. Cornwell, Schmidt, and Sickles (1988) have proposed an estimator which can be used to derive firm-specific and time-varying efficiency for single equation linear models. This estimator has not yet been generalized to handle a nonlinear system of equations.

A final test was conducted to determine if the current production technology was appreciably different from that of the 1954-79 period. This was done by using the estimated model from Aivazian, et al., (1987) with our data and recalculating the price elasticities and productivity measures.[21] We found that there was some difference in the productivity statistics; the Aivazian model yielded slightly larger productivity declines for all factors. However, elasticities are quite different. The own price elasticities for energy are nearly the same for the two models. For the other three inputs, our model yields considerably larger own price elasticities. There is even more dissimilarity between the two sets of cross price elasticities. With the Aivizian model, labor and energy are complements and all other input pairs are substitutes. Our model indicates labor and energy are substitutes, while the labor and compressor pair and energy and pipeline services pair are complements. Elasticities estimated by our model are all greater, except for the energy and pipeline services pair. It appears the firms have adopted more fuel-efficient compressors. The technology is now more pipeline intensive, which is not surprising since pipelines are the least flexible of the inputs.

V. Conclusions

The purpose of this paper has been to examine the production technology of the interstate natural gas pipeline industry under partial price deregulation under the NGPA. In addition, the

---

[21] Using the estimated Aivazian, et al. model and our sample data, the calculated summary statistics are: $n_L = -1.334$, $n_E = -2.950$, $n_H = -1.142$, $n_P = -.793$, $n_{LE} = -.012$, $n_{LH} = .642$, $n_P = .702$, $n_{EH} = .229$, $n_{EP} = 2.736$, $n_{HP} = .699$, APL = -.0377, APE = -.0097, APH = -.0364, APP = -.0338, and TFP = -.0412. The difference between these values and those estimated with our model stem from the significantly different α_{ij} parameter estimates and expense shares between the two models.

substitution possibilities and the effect of the change in regulation on productivity were studied. In general, the parameter estimates and summary statistics are as expected. The industry is characterized by substantial economies of scale. There appears to be significant differences in efficiency among firms in the sample.

We found that during the first six years of price deregulation, there has been a marked decline in productivity. The only firms which maintained positive productivity rates were those with relatively large and growing transport services for others. However, growth in throughput for others was no guarantee of productivity. Firms appear to be more efficient in their own use of energy, but less efficient in their use of labor and capital due to the fixed nature of these inputs. There appears to have been a shift in the structure of production technology. The industry became more pipeline intensive and energy saving. As output declined less compressor horsepower was required. Retired compressors were either not replace or were replaced by lower horsepower units.

TABLE 1

Summary of Hypothesis Tests

Model	Calculated Chi-Sq.	Critical Chi-Sq.
I. No Restrictions		
II. No Efficiency Differentials- $\beta_i = 0$, for all i	978.158	35.172
III. Cobb-Douglas Technology- $\alpha_{ij} = 0$, for all i,j	661.723	18.307
IV. No Technological Change- $\delta_t = 0$, $\delta_{tt} = 0$, $\delta_{ti} = 0$ for all i	223.358	12.592
V. Constant Returns to Scale- $\Theta = 1$	19.461	3.840

TABLE 2

Parameter Estimates for Model I

Θ	1.9670** (.2956)	α_{EH}	-.0163* (.0074)
β_o	14.8214** (.0743)	α_{EP}	-.0169** (.0062)
α_L	.0603** (.0042)	α_{HP}	-.1157** (.0135)
α_E	.0602** (.0074)	δ_{TL}	.0006 (.0007)
α_H	.1796** (.0120)	δ_{TE}	.0061** (.0012)
α_P	.6999** (.0140)	δ_{TH}	.0008 (.0020)
α_{LL}	.0250** (.0028)	δ_{TP}	-.0074** (.0023)
α_{EE}	.0475** (.0046)	δ_T	.0168 (.0314)
α_{HH}	.1240** (.0182)	δ_{TT}	-.0101 (.0055)
α_{PP}	.1515** (.0145)	γ_{EPOCH_1}	.0297 (.0298)
α_{LE}	-.0143** (.0025)	γ_{EPOCH_2}	.0286 (.0395)
α_{LH}	.0081 (.0049)		
α_{LP}	-.0188** (.0042)		

*Significant at 5 percent level.
**Significant at 1 percent level.

Standard errors are in parentheses. The subscripts L, E, H, and P are assigned to the coefficients labor, energy, compressor capital services, and pipeline capital services respectively.

TABLE 3

Elasticities for Model I

Long-Run
Demand Elasticities*

$n_L = -2.561$
$n_E = -3.187$
$n_H = -8.300$
$n_P = -2.279$

$n_{LE} = 1.910$
$n_{LH} = -4.013$
$n_{LP} = 4.664$
$n_{EH} = 4.032$
$n_{EP} = -2.179$
$n_{HP} = 7.695$

*Evaluated at estimated mean expenditure shares.

TABLE 4

Changes in Productivity

Annual Change in Total Productivity

	Estimated[a]	Observed[b]
1978	.0051	.0100
1979	.0204	.0171
1980	-.0166	-.0180
1981	-.0048	-.0082
1982	-.0859	-.0817
1983	-.0755	-.0753
1984	-.0017	.0026
1985	-.0799	-.0865

Average Change in Productivity

	Estimated[a]	Observed[b]
TOTAL	-.0298	-.0300
LABOR	-.0242	-.0226
ENERGY	.0007	.0025
COMPRESSOR	-.0227	-.0235
PIPELINE	-.0219	-.0245

[a] Based on estimated share values.
[b] Based on observed share values.

TABLE 5

Changes in Total and Factor Productivity, by Firm*

Firm	$A\dot{P}L$	$A\dot{P}E$	$A\dot{P}H$	$A\dot{P}P$	$T\dot{F}P$
Algonquin	.0352	-.1580	-.0013	.0148	.0206
ANR	.0117	.0154	-.0063	-.0062	-.0079
ARKLA	-.0128	-.0047	-.0270	-.0134	-.0103
Colorado Int.	-.0449	.0510	-.0766	-.0430	-.0605
Columbia Gas	-.0241	-.0533	-.0389	-.0428	-.0590
Columbia Gulf	.0218	-.0199	.0343	.0049	-.0136
Consolidated	-.0072	.0132	.0008	-.0084	-.0053
El Paso	.0091	-.0862	-.0245	-.0285	-.0290
Florida Gas	.0581	-.0073	.0442	.0379	.0353
Miss. River	-.0417	-.0231	-.0477	-.0521	-.0612
NGP of Amer.	-.0034	.0590	-.0024	-.0132	-.0312
Northern Nat.	.0303	.0039	.0140	.0289	.0661
NW Central	-.0482	.0325	-.0483	-.0448	-.0573
NW Pipeline	-.0023	.0521	-.0244	-.0192	-.0306
Panhandle E.	-.0978	-.0577	-.0663	-.0615	-.0714
Sea Robin	-.1763	.0547	-.0572	-.0655	-.0913
Southern Nat.	-.0157	.0012	-.0322	-.0257	-.0265
Tenneco	-.0254	.0565	-.0505	-.0400	-.0379
Texas Eastern	-.0043	-.0068	-.0255	-.0127	-.0299
Texas Gas	-.0172	.0305	-.0110	-.0068	-.0097
Transcontential	-.0081	-.0450	.0304	.0191	.0078
Transwestern	-.0619	-.0457	-.0146	-.0377	-.0679
Trunkline	-.0422	.1139	-.0361	-.0414	-.0600
United	-.1136	.0410	-.0789	-.0688	-.0856

*Based on estimated expenditure shares.

TABLE 6

Technical Efficiencies

Firm	Avg. Output BCF-Miles	Efficiency Rankings
NW Pipeline	235,425	1
Algonquin	42,094	2
Sea Robin	49,709	3
Consolidated	356,803	4
Colorado Inter.	208,547	5
Mississippi River	138,982	6
United Gas	733,009	7
Florida Gas	326,498	8
Transwestern	320,639	9
ARKLA	110,845	10
Columbia Gas	678,473	11
Trunkline	664,044	12
NW Central	748,162	13
Texas Gas	530,465	14
Southern Natural	416,305	15
Columbia Gulf	516,002	16
Panhandle Eastern	657,886	17
Northern Natural	495,229	18
ANR	856,336	19
Texas Eastern	2,051,674	20
El Paso Natural	948,076	21
Transcontinental	1,579,758	22
Tenneco	2,107,162	23
NGP of America	1,202,702	24

APPENDIX

We measure the output and input variables in a similar methodology as Aivazian, et al. (1987) in order to allow for comparisons between their study of the natural gas transmission industry during its years of expansion prior to the NGPA and our study of a mature industry coping with shrinking markets and a different regulatory environment. Data are from the 1977-85 firm specific FERC Form-2: Annual Report of Major Natural Gas Pipeline Company, supplemented with the Annual Statistics of Interstate Natural Gas Pipeline Companies (ASI) unless otherwise indicated. The FERC Form-2 contains very detailed information on the financial and operating expenses of the pipeline company, as well as a breakdown of types of output and sources of revenues earned. These reports are not generally distributed, but are available through the Public Information Office at FERC.

Output is measured in billion cubic feet-miles, derived by multiplying the total volume of gas delivered under "sales for resale", "mainline sales", and "transport of gas of others" by the miles transported. Gas quantities were extracted from the "Gas Accounts-Deliveries" schedule. As miles transported are not reported for resale and mainline sales. we use the average length of the major transmission trunklines from the main production area(s) to the major delivery point(s) for these two categories. The mileage figures are calculated with the use of firm specific pipeline system maps. The weighted average miles transported for gas transported for others is calculated from the "Revenue from Transportation of Gas of Others" schedule.

The quantity of labor is calculated by multiplying the total number of firm employees by the proportion of transmission labor expenses relative to total labor expenses, from the "Distribution of Wages and Salaries" schedule. Energy (natural gas) consumed in production is measured in thousand cubic feet (mcf), as reported in the "Gas Used by the Utility" schedule. The expense for energy consumed are from the Transmission Expense section of the "Operations and Maintenance Expense" schedule. The price of labor and energy are derived by dividing total labor and energy expenses by their respective quantities.

Two measures of capital input are used: total horsepower ratings of transmission compressor stations as a proxy for compressor capital services and tons of steel as a proxy for pipeline services. In measuring the quantity of compressor and pipeline capital services used in production, we had to draw on additional data sources as the horsepower rating and pipeline diameters are often not explicitly reported in the <u>FERC Form-2</u> after 1979. To determine total horsepower and pipeline diameter after 1979 we turned to the "Pipeline Economics Report" published in the <u>Oil and Gas Journal</u>. The <u>OGJ</u> "Pipeline Economics Report" is published once a year, usually in November, and contains data on the configuration and cost of current pipeline and compressor station construction. Data are given, by state, for specific projects. By comparing the location of the individual projects in the <u>OGJ</u> with the areas of operation for each firm and information from the <u>FERC Form-2</u>, we are usually able to determine which company is undertaking which project.

Beginning with the horsepower total for 1979, this quantity is up dated for each successive year by close examination of information in the "Compressor Stations" schedule and Section 5 of the "Important Changes During the Year", both in the FERC Form-2. This information is checked against the information given in the OGJ. In a similar fashion, we are able to obtain the weighted average diameter of the pipelines after 1979. The size and length of additional transmission lines, or abandon segments, was often specified in the FERC Form-2 "Transmission Lines" or "Important Changes During the Year" schedules, or the pipeline projects from the OGJ. Thus, the miles of transmission pipeline is multiplied by the weighted average diameter, and then by Callen's proportionality constant for converting size and length into ton-miles. Since the firms have not significantly expanded their pipeline systems during the period of study, the method of calculating horsepower and pipeline diameter is not as cumbersome as might be expected.

Neither prices not expenses for capital services is directly reported; we rely on the value added methodology. First, total revenues from sales for resale, mainline sales, and transport of gas of others are obtained from the "Gas Operating Revenues" schedule. The cost of labor, energy, and gas purchased are netted out. This net revenue was allocated between compressor and pipeline services based on the ratio of book value cost and operating costs of compressors to pipelines (referred to as "mains"). End of year book value costs are from the Transmission Plant section of the "Gas Plant in Service" schedule. The operating and maintenance costs are from the Transmission Expenses section of the "Gas Operation and Maintenance Expenses" schedule. The resulting two residuals are divided by the appropriate quantity, horsepower or pipeline steel tons, to obtain user prices for the two capital categories.

BIBLIOGRAPHY

Aivazian, Varouj A., Jeffrey L. Callen, M.W. Luke Chan, and Dean C. Mountain. "Economies of Scale Versus Technological Change in the Natural Gas Transmission Industry." Review of Economics and Statistics 69, no. 3 (Aug. 1987): 556-561.

Aivazian, Varouj A. and Jeffrey L. Callen. "Capacity Expansion in the U.S. Natural Gas Pipeline Industry." Productivity Measurements in Regulated Industries. Ed. Thomas G. Cowing and Rodney E. Stevenson. New York: Academic Press, 1981.

Berndt, Ernst R., and Laurits R. Christensen. "The Translog Function and the Substitution of Equipment, Structures, and Labor in U.S. Manufacturing 1929-68." Journal of Econometrics 1 (March 1973): 81-114.

Callen, Jeffrey L. "Production, Efficiency, and Welfare in the Natural Gas Transmission Industry." American Economic Review 68, no. 3 (June 1978): 311-323.

Carpenter, Paul Roger. "Natural Gas Pipelines After Field Price Decontrol." MIT Energy Laboratory Report No. MIT-EL 84-004, MIT Center for Energy Policy Research, March 1984.

Chan, M.W. Luke, and Dean C. Mountain. "Economies of Scale and the Tornqvist Discrete Measure of Productivity Growth-A Study of the Canadian Agricultural Sector." Review of Economics and Statistics 65. no. 3 (Nov. 1983): 663-667.

Christensen, Laurits, R., Dale W. Jorgenson and Lawrence J. Lau. "Transcendental Logarithmic Production Frontiers." Review of Economics and Statistics 55, no. 1 (Feb. 1973): 28-45.

Cornwell, C., Peter Schmidt, and Robin C. Sickles. "Production Frontiers with Cross-Sectional and Time-Series Variation in Efficiency Levels." Mimeo, Rice University, Houston, Texas, 1988.

Fanara, Jr., Philip and David M. Sweet. "What Do Regulated Firms Maximize? Some Empirical Evidence From the Natural Gas Pipeline Industry." American Economist 28, no. 1 (Spring 1984): 44-48.

Federal Energy Regulatory Commission. U.S. Department of Energy. FERC Form No. 2: Annual Report of Natural Gas Companies (Class A and Class B). Washington, D.C.: U.S. Government Printing Office, 1977-1985.

Federal Energy Regulatory Commission. U.S. Department of Energy. Statistics on Interstate Natural Gas Pipeline Companies. Washington, D.C.: U.S. Government Printing Office, 1978-1986.

Gollop, Frank M., and Dale W. Jorgenson. "U.S. Productivity Growth by Industry, 1947-73." *New Developments in Productivity Measurement and Analysis*. Ed. John W. Kendrick and Beatrice N. Vaccara, Chicago: University of Chicago Press, 1980.

Gollop, Frank M. and Mark J. Robert. "The Sources of Economic Growth in the U.S. Electric Power Industry." *Productivity Measurement in Regulated Industries*. Ed. Thomas G. Cowing and Rodney E. Stevenson, New York: Academic Press, 1981.

Jorgenson, Dale W., and Barbara M. Fraumeni. "Relative Prices and Technical Change." *Modeling and Measuring Natural Resource Substitution*. Ed. Ernst R. Berndt and Barry C. Field, Cambridge, Mass.: MIT Press, 1981.

Natural Gas Monthly. Merrill Lynch, Pierce, Fenner & Smith Incorp., various issues, 1978-1986.

Natural Gas Policy Act of 1978. U.S. Code, Supp. 5, Title 15, 1980.

Nelson, Randy A. and Mark E. Wohar. "Regulation, Scale Economies, and Productivity in Steam-Electric Generation." *International Economic Review* 24, no. 1 (Feb. 1983): 57-79.

Pierce, Jr., Richard J. *Natural Gas Regulation Handbook*. New York: Executive Enterprises Publication, 1980.

Robinson, S.T. "Powering of Natural Gas Pipelines." *Journal of Engineering for Power* (July 1972): 181-186.

Schmidt, Peter and D. Wyhowski. "Simultaneous Equations and Panel Data." Mimeo, Michigan State Univ., East Lansing, Michigan, 1988.

Schmidt, Peter, and Robin C. Sickles. "Production Frontiers and Panel Data. *Journal of Business and Economic Statistics* 2 (1984): 367-74.

Stich, Robert S. and L. Douglas Smith. "Federal Regulation of Gas Pipeline Rate, 1973-1982." *Public Utilities Fortnightly* (Jan. 19, 1984): 34-38.

True, Warren R. "Pipeline Economics Report." *Oil and Gas Journal* (November issues, 1978-1987).

Zellner, A., J. Kmenta and J. Dreze. "Specification and Estimation of Cobb-Douglas Production Function Models." *Econometrica* 34, no. 4 (Oct. 1966): 784-795.