LOCAL MONOPOLY, NETWORK EFFECTS AND TECHNICAL EFFICIENCY – EVIDENCE FROM TAIWAN'S NATURAL GAS INDUSTRY

Ting-Kun Liu, Chaoyang University of Technology

ABSTRACT

This paper examines the optimal number of natural gas firms in each region of Taiwan. In order to separate large local monopoly companies from the small ones, this paper constructs a firm-level panel data analysis for the industry covering the period 1995-1999. The optimal number of firms in each region is estimated by using the minimum efficient scale theory. In addition, a non-neutral stochastic frontier production function is used to detect the impact of the local monopoly, the network effects and cost structure on the natural gas firms' technical efficiency.

JEL: D42, L95, O30

KEYWORDS: Local monopoly, network effect, non-neutral stochastic frontier production function, technical efficiency, natural gas industry

INTRODUCTION

According to the energy statistics of the Bureau of Energy of the Ministry of Economic Affairs (2005), a total of 9,373 million cubic meters (Nm^3) of liquefied natural gas (LNG) was imported into Taiwan in 2005. When compared with the 856 million Nm^3 imported in 1990, this represents an average annual growth rate of 17.30%. The level of LNG consumption, this rose from 606 million Nm^3 in 1990 to 8,674 million Nm^3 in 2005. Of this quantity consumed, some 87.50% was for electricity usage, 9.88% for industry, 1.71% for residents, 0.83% for businesses and 0.08% for others.

The production of natural gas amounted to 1,327 million Nm^3 in 1985 declining to 547 million Nm^3 in 2005. The amount consumed was 1,391 million Nm^3 in 2005 compared with 1,130 million Nm^3 in 1985. The average annual growth rate was 1.05%. This study reveals that the consumption of natural gas has exhibited an increasing trend and implies that the usage of natural gas has gradually been adopted by the country. In view of the limitations regarding the supply of domestic natural gas energy, Taiwan depends increasingly on imports of natural gas.

Compared to coal and petroleum, natural gas is a source of energy with low carbon and it is clean. It produces no SO_X when burning. It produces only 20-40% of NO_X and 60% of CO_2 with less air pollution than coal. Faced with the requirement to reduce CO_2 emissions in accordance with the "Kyoto Protocol", the Taiwan government has introduced low-polluting energy policies and has extended the usage proportions of low-polluting energy sources such as natural gas. For example, the authority plans to abolish the imposition of a tariff and commodity tax on natural gas, encourage the utilization of natural gas by taxing coal, and replace coal with natural gas to generate electric power. Since the ratio of natural gas to the total amount of domestic energy is only 8%, there is still room to push for an increase in the use of natural gas.

In 2005, there were 25 local natural gas firms in Taiwan. Each was established at a different time and are spread out across different operating locations. Although the total number of firms differs from region to region, the natural gas industry in Taiwan is a chartered industry that causes the operation of each firm to be similar to that of a local monopoly. However, to our knowledge few studies consider this characteristic. Burton (1994), Bernard and Weiner (1996), Raphael (1998), Gort and Sung (1999) and Filippini and Wild (2001) discuss the insecticide, petroleum, telecommunications, telephone and electricity industries, respectively, without referring to the natural gas industry. The industry requires huge capital investments and firms must endure both large and long-term losses in their initial stages of operation. According to Chen *et al.* (2005) natural gas firms in Taiwan make a profit but do not operate at an optimal level. It is thus necessary to further examine and evaluate the productivity and technical efficiency of these firms to improve their productivity and operating efficiency.

Due to higher population concentrations and urbanization, it is cheaper to set up the necessary piping in the north than in the south of Taiwan. The regions that use natural gas are all located along the western corridor of Taiwan, and for geographical and environmental reasons, there are no such firms in eastern Taiwan. The differences in calorific values are also a reason for the divergence in terms of the firms' cost structures (i.e., the price of self-produced gas is lower than imported gas and has a lower calorific value). Caves (1984) explored the network-related industries and indicated that cost was not only affected by inputs, but was also affected by network variables. Network effects may be divided into the network configuration and network utilization. The network configuration represents the spread of subscribers and air feed, and network utilization refers to the facilities' utilization rate. Due to difficulties in obtaining network utilization data, this variable has rarely been adopted in previous studies. With regard to network configuration, related studies focus on the length of railroad for transportation or service stations for the air transportation industry. Salvanes and Tjotta (1994) and Jang *et al.* (1997) study the electricity industry and both adopt the number of subscribers as a proxy for the network variable. For this reason, this paper applies the number of natural gas subscribers as a proxy for the network variable in order to measure the network effects.

The remainder of the paper is organized as follows. The literature is reviewed in Section 2. Section 3 describes empirical data and methodology of this study. Section 4 presents the empirical results, and the final Section contains concluding remarks.

LITERATURE REVIEW

Papers that discuss productivity and technical efficiency have not been seen in Taiwan and only a few are found abroad, including Sing (1986), Aivazian *et al.* (1987) and Chermak and Patrick (1995). Aivazian *et al.* (1987) found that, in addition to technical change, the other contributing factor to productivity of the U.S. natural gas industry is its economies of scale. Aivazian *et al.* (1987) confirmed the impact of economies of scale on the productivity of the natural gas industry. Differing from Aivazian *et al.* (1987), this paper refers to Chen *et al.* (2005) by applying the minimum efficient scale (MES) theory to estimate the optimal number of natural gas firms in each location.

A major difference between this study and previous studies on the cost-side in the energy or network industry is that this paper applies a production function. For example, Nemoto *et al.* (1993), Bhattacharyya *et al.* (1995) and Jang *et al.* (1997) used a cost function in their empirical analysis in studies of the air transportation, hydropower, electric power and telecommunications industries. With regard to the definition of a network industry, see White (1996). In the literature on natural gas (Sing, 1986; Chermak and Patrick, 1995), use a cost function to construct an empirical model. This paper applies the non-neutral stochastic frontier production function model defined by Wang and Schmidt (2004) and developed by Huang and Liu (1994) to investigate the impact of the non-neutral effects of natural gas firms' characteristic variables on production function frontiers and efficiency. For empirical studies on the Taiwanese electronics and banking industries that apply the non-neutral stochastic frontier production function, please refer to Chen (2001) and Huang (2005). Furthermore, this paper distinguishes between large and small local monopolies, and takes network effects and cost structure into consideration to identify differences in technical efficiency between large and small local monopolies.

DATA AND METHODOLOGY

Survey data were obtained from a plan drawn up by the Bureau of Energy of the Ministry of Economic Affairs (MOEA) and implemented during 1995-1999. From these data, we are able to construct a balanced panel dataset of 21 Taiwanese natural gas firms for the 1995-1999 survey periods. The sample statistics for our key variables are provided in Table 1.

Table 1: Statistics for Variables (after Deflation by the 2005 Price Index)

Variable	Name	Unit NT$	Mean	Standard Error
Variable Cost	*VC*	thousands	474,304.52	560,046.04
Output of gas	Q_1	thousands	426,918.16	490,286.36
Output of device	Q_2	thousands	189,963.82	164,175.22
Price of gas	P_1	Nm^3/NT$	12.30	1.01
Price of device	P_2	thousands	19,139.14	14,727.57
Price of labor	P_3	thousands	867.67	300.86
Physical capital	*K*	thousands	929293.07	967441.90
Number of subscribers	*N*	household	78432.72	81372.35
Total sales	*Y*	thousands	631,189.63	614,003.02
Physical capital	*Cap*	thousands	929293.07	967441.90
Price of labor	*Lab*	thousands	867.67	300.86
Expenditure on material	*Mat*	thousands	38,340,829.38	44,661,880.37
Dummy variable	*Loc*	Larger local monopoly=1, otherwise=0		
Number of subscribers	*Net*	household	78432.72	81372.35
Operating cost	*Cost*	thousands	473,856.59	557,365.91

Notes: The survey data were obtained from a plan drawn up by the Bureau of Energy of the Ministry of Economic Affairs (MOEA) and *implemented during 1995-1999.* This table shows sample statistics for our key variables.

ESTIMATION OF THE MINIMUM EFFICIENT SCALE (MES)

This paper estimates the average MES production by using a short-term translog cost function under the output mode of selling both gas and devices. In addition, since geographical features easily affect the optimal number of firms, this paper divides the Taiwan market into the northern, central and southern regions and evaluates the optimal number of firms using MES. The firms that merge in each region are the larger local monopoly firms. When calculating the MES, we assume that the quantities of devices sold are given and use the sample average as the proxy variable. The estimated equation may then be expressed as follows:

$$E^C = \frac{\partial \ln VC}{\partial \ln Q_1} \tag{1}$$

where E^C is the short-term cost elasticity when $E^C = \partial \ln VC / \partial \ln Q_1 = 1$ is the condition for attaining the MES (Fuss and Gupta, 1981; Elhendy and Alzoom, 2001). Q_1 is the output of gas, and *VC* represents the variable cost, which is specified as:

$$\begin{aligned}\ln VC &= \beta_0 + \sum_{i=1}^{3}\beta_{P_i}\ln P_i + \sum_{i=1}^{2}\beta_{Q_i}\ln Q_i + \beta_K \ln K + \beta_N \ln N + \beta_T T \\ &+ \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3}\beta_{P_iP_j}\left(\ln P_i \ln P_j\right) + \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2}\beta_{Q_iQ_j}\left(\ln Q_i \ln Q_j\right) \\ &+ \frac{1}{2}\beta_{KK}(\ln K)^2 + \frac{1}{2}\beta_{NN}(\ln N)^2 + \frac{1}{2}\beta_{TT}(T)^2 \\ &+ \sum_{i=1}^{3}\sum_{j=1}^{2}\beta_{P_iQ_j}\ln P_i \ln Q_j + \sum_{i=1}^{3}\beta_{P_iK}\ln P_i \ln K \\ &+ \sum_{i=1}^{3}\beta_{P_iN}\ln P_i \ln N + \sum_{i=1}^{3}\beta_{P_iT}\ln P_i T + \sum_{i=1}^{2}\beta_{Q_iK}\ln Q_m \ln K \\ &+ \sum_{i=1}^{2}\beta_{Q_iN}\ln Q_i \ln N + \sum_{i=1}^{2}\beta_{Q_iT}\ln Q_i T + \beta_{KN}\ln K \ln N \\ &+ \beta_{KT} T \ln K + \beta_{NT} T \ln N + \varepsilon \end{aligned} \quad (2)$$

where P_1, P_2 and P_3 are the prices of gas, devices and labor, respectively. K represents a fixed input of capital, N is the number of subscribers serving as the proxy for the network effects, i and T are the firm and time trend, respectively, and Q_2 is the output of the devices.

THE NON-NEUTRAL STOCHASTIC FRONTIER PRODUCTION FUNCTION

A stochastic frontier production function in translog form with three input variables is formulated as follows:

$$\ln(\eta) = \beta_0 + \sum \beta_i \ln(X_i) + \sum \beta_i (X_i) + \frac{1}{2}\sum\sum \beta_{ij} \ln(X_j) + v \quad (3)$$

where η is the stochastic frontier output, and the X's are the total wage bill (*Lab*), the value of fixed capital assets (*Cap*) and total expenditure on materials (*Mat*), respectively. The firm's characteristics, i.e., the scale of the local monopoly (*Loc*), network effects (*Net*), and the cost structure (*Cost*), are identified as sources of efficiency in production. The interaction between a firm's characteristics and input usage results in non-neutrality in terms of productivity and efficiency. The non-neutral efficiency function with interaction is of the form:

$$\ln(Y) - \ln(\eta) = \sum \alpha_i Z_i + \sum\sum \alpha_{ij} Z_i \ln(X_j) + w \quad (4)$$

where $\alpha_{ij}= 0$ in equation (4) represents the neutral efficiency function in which the interaction terms do not exist, otherwise the interaction between a firm's characteristics and input usage results in the non-neutrality of productivity. Y is the firm's total sales. With the truncated normal distribution for w, it is easily shown that an individual firm's mean technical efficiency $E(Y/\eta)$ in equation (5) is equal to:

$$E\left(\frac{Y}{\eta}\right) = \exp\left[\sigma_w + \left(\rho + \frac{1}{2}\sigma_w\right)\right]\frac{1-\Phi(\sigma_w + \rho)}{1-\Phi(\rho)} \quad (5)$$

where

$$\rho = \frac{\sum \alpha_i Z_i + \sum\sum \alpha_{ij} Z_i \ln(X_j)}{\sigma_w} \quad (6)$$

The industry-wide mean technical efficiency is then the average of the individual firm's mean technical efficiency. The specification of the efficiency function in equation (4) allows for the non-neutral shift in observed output from the frontier. The marginal effect of Z_i on the expected production efficiency is a function of input X_j

$$\frac{\partial E\left(\frac{Y}{\eta}\right)}{\partial Z_k} = \psi\left[\alpha_k + \sum \alpha_{kj} \ln(X_j)\right] E\left(\frac{Y}{\eta}\right) \tag{7}$$

where

$$\psi = \left[\sigma_w + \frac{\phi(\xi)}{1-\Phi(\xi)} - \frac{\phi(\sigma_w + \xi)}{1-\Phi(\sigma_w + \xi)}\right]\frac{1}{\sigma_w} \tag{8}$$

Finally, the returns to scale in production can be calculated as:

$$\sum \frac{\partial \ln E(Y)}{\partial \ln(X_k)} = \sum \left[\beta_k + \sum \beta_{kj} \ln(X_j)\right] + \psi \sum\sum \alpha_{jk} Z_j \tag{9}$$

The first part of the right-hand side of the equation is the returns to scale corresponding to a neutral specification of the production function, i.e., $\alpha_{jk} = 0$ for all j and k.

EMPIRICAL RESULTS

The cost function model consisting of equation (2), with restrictions in terms of homogeneity in input prices, symmetry, and its adding up property, was estimated using panel data for the period 1995-1999. As noted above, in the model estimation, the cost-share equation for capital was deleted. The parameter estimates and the associated asymptotic t-values are presented in Table 2. This paper then estimates the average MES production by using a short-term translog cost function under the output mode of selling both gas and related devices, and obtains an optimum average MES of 176,952,000 Nm^3.

By using the average amount of natural gas sales as the market demand for the 5 survey years, this paper can measure the optimal number of firms in each region. In the northern region, the optimal number of firms is 3.39 according to the average quality of sales of 600 million Nm^3. The optimal number of firms is 1.27 in the central region according to the average quality of sales of 225 million Nm^3. In the southern region, the average quality of sales is 131 million Nm^3 and the optimal number of firms is 0.74. We thus conclude that under the optimal production scale in Taiwan's natural gas industry, the optimal number of firms should be 3, 1 and 1 in the northern, central and southern regions, respectively. These empirical results also provide us with the number of large local monopoly firms for further analysis.

The maximum-likelihood method is used to estimate the translog frontier (3) and the efficiency (4) functions. The estimates of the translog frontier function and of the efficiency function are presented in Table 3. All estimates are statistically significant at the 10% level, with the exception of the coefficients $\beta_{MatMat,}$ and $\alpha_{CostMgt}$.

Table 2: Estimation of Translog Cost Function (1995-1999)

Variable	Coefficient	Variable	Coefficient
Constant	8.042 (3.436) ***	$ln\ P_1\ ln\ N$	-0.065 (-3.421) ***
$ln\ P_1$	0.192 (0.580)	$ln\ P_1\ ln\ T$	0.004 (0.295)
$ln\ P_2$	0.398 (3.670) ***	$ln\ P_3\ ln\ P_2$	-0.001 (-0.077)
$ln\ P_3$	0.410 (1.265)	$ln\ P_3\ ln\ Q_1$	-0.102 (-5.257) ***
$ln\ Q_1$	-1.325 (-3.436) ***	$ln\ P_3\ ln\ Q_2$	0.066 (4.030) ***
$ln\ Q_2$	-0.274 (-1.238)	$ln\ P_3\ ln\ K$	0.060 (4.464) ***
$ln\ K$	-0.421 (-1.888) *	$ln\ P_3\ ln\ N$	-0.039 (-2.557) ***
$ln\ N$	2.837 (9.008) ***	$ln\ P_3\ ln\ T$	0.004 (1.264)
$ln\ T$	-0.339 (-5.443) ***	$ln\ P_2\ ln\ Q_1$	-0.053 (-3.480) ***
$(ln\ P_1)^2$	0.007 (0.205)	$ln\ P_2\ ln\ Q_2$	0.007 (0.768)
$(ln\ P_2)^2$	-0.005 (-0.186)	$ln\ P_2\ ln\ K$	0.005 (0.654)
$(ln\ P_3)^2$	0.013 (1.347)	$ln\ P_2\ ln\ N$	0.035 (2.324) **
$(ln\ Q_1)^2$	0.446 (10.901) ***	$ln\ P_2\ ln\ T$	-0.004 (-1.542)
$(ln\ Q_2)^2$	0.046 (2.835) ***	$ln\ Q_1\ ln\ Q_2$	-0.040 (-1.965) **
$(ln\ K)^2$	0.019 (2.065) **	$ln\ Q_1\ ln\ K$	-0.025 (-2.405) ***
$(ln\ N)^2$	0.284 (6.720) ***	$ln\ Q_1\ ln\ N$	-0.312 (-7.838) ***
$(ln\ T)^2$	-0.001 (-0.255)	$ln\ Q_1\ ln\ T$	0.039 (6.946) ***
$ln\ P_1\ ln\ P_3$	0.006 (0.194)	$ln\ Q_2\ ln\ K$	-0.017 (-1.940) *
$ln\ P_1\ ln\ P_2$	-0.012 (-1.077)	$ln\ Q_2\ ln\ N$	0.007 (0.374)
$ln\ P_1\ ln\ Q_1$	0.155 (5.954) ***	$ln\ Q_2\ ln\ T$	-0.004 (-1.498)
$ln\ P_1\ ln\ Q_2$	-0.073 (-4.326) ***	$T\ ln\ N$	-0.029 (-4.376) ***
$ln\ P_1\ ln\ K$	-0.054 (-4.321) ***		

This table presents the parameter estimates and the associated asymptotic t-values of the translog cost function model. The translog cost function model consisting of equation (2). *The numbers in parentheses are T values. The terms ***, **, and * represent the 1%, 5%, and 10% significance levels, respectively.* R^2 of Cost function 0.994, R^2 of Gas share 0.848, R^2 of Labor share 0.839

Table 3: Estimation of MLE (1995-1999)

Stochastic frontier production function		**Non-neutral efficiency function**	
Variable	**Coefficient**	**Variable**	**Coefficient**
B_0	0.300 (10.125)***	α_{Loc}	0.210 (6.725)***
B_{Lab}	-0.084 (-6.186)***	α_{Net}	0.034 (5.109)***
B_{Cap}	0.022 (5.045)***	α_{Cost}	0.122 (4.000)***
B_{Mat}	0.023 (1.741)*	α_{LocLab}	0.223 (1.741)*
B_{LabLab}	-0.217 (-8.188)***	$\alpha_{LoctCap}$	-0.017 (-6.702)***
β_{LabCap}	-0.474 (-4.282)***	$\alpha_{LoctMat}$	0.266 (3.882)***
B_{LabMat}	1.491 (3.924)***	α_{NetLab}	0.795 (4.743)***
β_{CapCap}	-0.204 (-4.235)***	$\alpha_{NettCap}$	0.204 (3.442)***
β_{CapMat}	0.112 (2.219)**	α_{NetMat}	-0.335 (-2.002)**
B_{MatMat}	0.053 (1.001)*	$\alpha_{CostLab}$	0.198 (1.800)*
		$\alpha_{CostCap}$	0.383 (1.926)*
		$\alpha_{CostMat}$	0.403 (1.501)*
σ^2_y	-0.082 (-6.064)***	σ^2_w	0.136 (3.064)***

This table provides the estimations of maximum-likelihood method to estimate the translog frontier (equation (3)) and the efficiency function (equation (4)). Numbers in parentheses are T values. The terms ***, **, and * represent the 1%, 5%, and 10% significance levels, respectively.

Panel A of Table 4 presents the results for the small and large local monopoly firms' mean technical efficiency. The results show that the large local monopoly firms' mean technical efficiency is higher than that of the small local monopoly firms. This coincides with Chen *et al.* (2001) who find that large firms have a higher mean technical efficiency than small firms in the electronics industry. By observing the impact of firms' characteristics on the marginal effect of technical efficiency, we see that the marginal effects of the firms' scale and network effects are higher in large local monopoly firms than in small local monopoly firms as shown in Panel B of Table 4. In other words, when large local monopoly firms extend their scale then the economies of scale they obtain are significantly better than in the case of small local monopoly firms. This implies that firms in the natural gas industry can enhance their technical efficiency by enlarging their scale. Furthermore, the small local monopoly firms' marginal effect of scale is negative which could be the reason why some firms' exploitation of capacity is restricted by scale, which raises the operating costs and is unfavorable to the improvement of technical efficiency. In general, Panel B of Table 4 reveals that large local monopoly firms have higher technical efficiency due to the large firms having greater scale and network effects. Panel C of Table 4 shows estimates of the returns to scale.

The small local monopoly firms in the Taiwanese natural gas industry are close to exhibiting constant returns to scale. This implies that Taiwan's natural gas industry is presently characterized by constant returns to scale. If Taiwan can adopt the mode of a large local monopoly, then increasing returns to scale could be obtained in the natural gas industry.

Table 4: Estimations of Mean Technical Efficiency, Marginal Effects and Average Returns to Scale

Panel A			
Firms	**Technical Efficiency**	**Standard Error**	**Sample**
Large local monopoly	0.7139	0.060	21
Small local monopoly	0.7162	0.045	5
Panel B			
Firms	**Scale**	**Network Effects**	**Cost**
Large local monopoly	-0.0445	0.0009	0.6562
Small local monopoly	0.0362	0.0726	0.5873
Panel C			
Firms	**Return to Scale**	**Standard Error**	**Sample**
Large local monopoly	0.9761	0.1352	21
Small local monopoly	1.4429	0.2342	5

Notes: Panel A presents the results of Mean Technical Efficiency of Large and Small Local Monopoly Firms, Panel B are Marginal Effects of Firms' Characteristics, and Panel C shows the Average Returns to Scale of Large and Small Local Monopoly Firms.

CONCLUSION

The most significant difference between previous studies on the cost-side in the energy or network industry in this paper is that it applies a production function (for example, see Nemoto *et al.* (1993), Bhattacharyya *et al.* (1995) and Jang *et al.* (1997). In the literature on natural gas (Sing, 1986; Chermak and Patrick, 1995), a cost function is used as an empirical model. This paper applies the non-neutral stochastic frontier production function model to investigate the impact of the non-neutral effects of natural gas firms' characteristic variables on the production function frontier and efficiency. Furthermore, this paper distinguishes large from small local monopolies, and takes the network effects and cost structures into consideration in order to compare the differences in technical efficiency between large and small local monopolies.

The results show that the mean technical efficiency of large local monopoly firms is higher than that of small local monopoly firms. This finding coincides with that of Chen *et al.* (2001). By observing the impact of firms' characteristics on the marginal effect of technical efficiency, we find that the marginal effects of the firms' scale and network effects are higher in large local monopoly firms than in small local monopoly firms. In general, the large local monopoly firms have higher technical efficiency due to the large firms having greater scale and network effects. This implies that constant returns to scale currently exist in Taiwan's natural gas industry. If we can adopt the mode of large local monopolies, then increasing returns to scale can be achieved in the natural gas industry.Our empirical results should be good reference material for other developing countries. However, with the limitations of data resources we are limited by sample size. In future studies, the comparison of different industries and periods could be completed to provide additional insights.

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BIOGRAPHY

Dr. Ting-Kun Liu is an Assistant Professor of Finance at Chaoyang University of Technology. His research interests include information technology, E-commerce management and applied econometrics. He can be contacted at: Department of Finance, Chaoyang University of Technology, 168 Gifong E. Rd., Wufong Township, Taichung County, 41349, Taiwan. Email: tkliu@cyut.edu.tw.