A STUDY OF THE PRODUCTION FEATURES AND RELATIVE EFFICIENCY OF R&D ACTIVITIES: EVIDENCE FROM HIGH-TECH INDUSTRIES

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ABSTRACT

This paper considers that firms employ R&D manpower and physical resources as inputs and produce patents and R&D-induced profits as outputs. Functional forms and various types of elasticity are estimated. Stochastic frontier techniques are applied to evaluate the efficiency scores with control over the operating environment. High-tech firms in Taiwan of recent years are examined. Results show that possibility of substitution between R&D input factors is slim. High efficiency levels are achieved in most firms when environmental factors are taken into account.

INTRODUCTION

The purpose of this paper is two-fold. The first is to estimate the production function of R&D activities as well as various types of elasticity for the high-tech firms. To explore the possibility of substituting one R&D input for another is considered to be beneficial to the firm's policy making in its resource allocation. The second is to place emphasis on the efficiency of R&D resource utilization by proposing an approach that evaluates R&D across firms. Efficiency evaluations along with analyses in terms of environmental effects provide useful information regarding the degree of efficiency. Particularly, we intend to investigate the effects of firm size and foreign capital share on the R&D performance.

By assuming that each firm in a high-tech industry is a decision making unit (DMU), which employs R&D manpower and physical/financial resources as inputs and produces patents and R&D-induced profits as tangible outputs, this paper constructs a translog production model for the R&D activities of 31 firms in a science industrial park in Taiwan covering the period 1999-2004. We further evaluate the relative technical efficiency of R&D activities across firms during the sample period by means of various stochastic production frontier techniques. In addition to the data envelopment analysis (DEA) technique, the stochastic frontier analysis (SFA) method has applied the econometric technique to estimating various production/cost frontiers.

THE EMPIRICAL METHODOLOGY: A STOCHASTIC R&D PRODUCTION FUNCTION

R&D Production Function

Each firm is to be regarded as a DMU that employs R&D capital and researchers as inputs to produce patents and R&D-induced profits as outputs in its innovative R&D process. A translog production function is assumed.

The Stochastic Frontier Approach for R&D Efficiency

Battese and Coelli [1] have proposed a time-varying model for evaluating technical efficiency.

$$y_{kt} = f(x_{kt}) + (V_{kt} - U_{kt}) \qquad k = 1, \ldots, K, \qquad t = 1, \ldots, T \tag{1}$$

The V_{kt} are random variables which are assumed to be iid $N(0, \sigma_V^2)$, and independent of the

$$U_{kt} = \{\exp[-\eta (t-T)]\} U_k \tag{2}$$

where the U_{kt} are non-negative random variables, which are assumed to account for technical inefficiency in production and are assumed to be iid as truncations at zero of the $N(\mu, \sigma_U^2)$ distribution. The ability of a production unit to transform inputs into outputs is affected not only by its technical efficiency but also by exogenous environmental factors. Battese and Coelli [2] proposed a technical efficiency frontier model, which accounts for factors that may influence the efficiency of a production unit and permits the use of panel data. It may be specified as:

$$y_{kt} = f(x_{kt}) + (V_{kt} - U_{kt}) \qquad k = 1, \ldots, K, \quad t = 1, \ldots, T \qquad (3)$$

The U_{kt} are non-negative random variables, assumed to account for technical inefficiency in production and are assumed to be iid as truncations at zero of the $N(m_{kt}, \sigma_U^2)$ distribution, where $m_{kt} = z_{kt}\,\delta$, where z_{kt} is a vector of environmental variables, which may affect the efficiency of a production unit and δ is a vector of parameters to be estimated.

HIGH-TECH INDUSTRIES in TAIWAN AND DATA DESCRIPTIONS

The SFA model is applied to a sample selected from the Hsinchu Science Park (HSP) in Taiwan.

Data Descriptions

The sample of 31 high-tech firms in the HSP was included in the study. The major inputs considered in the R&D process are manpower and the stock of capital. A simultaneous equations system is set up to estimate the relationships among R&D investment, granted patents, and annual profits before tax. The estimated parameters are then used to construct the index of R&D output. See Table 1. This study assumes the time lag to be two years. The input data sets for 1999, 2000, 2001 and 2002 are used to match with the output data sets for 2001, 2002, 2003 and 2004, respectively.

EMPIRICAL RESULTS

Estimation Results of the R&D Translog Production Function

Pooled time-series and cross-section regressions estimations based on the entire sample and on the IC sub-sample are performed separately. The results are presented in Table 2. Both the plain model and the fixed-effects model using the time dummy variables fit the data very well in accordance with the adjusted R-squares and F-values for the entire sample and the IC sub-sample. Upon estimating the translog form of the R&D activity, the output elasticity, scale elasticity, and elasticity of substitution are calculated. Descriptive statistics for the elasticity of the entire sample and the IC sub-sample are summarized in the lower panel of Table 3. Results show that possibility of substitution between R&D input factors is slim.

R&D Efficiency without Accounting for Environmental Factors

The results of the estimation for technical efficiency of R&D without accounting for environ-mental factors are presented in Table 4. It is seen that the mean level of the efficiency scores for the entire sample was quite low for all four periods.

R&D Efficiency in Accounting for Environmental Factors

Among the environmental factors, the number of employees, which indicates the size of the firm, and the share of foreign capital, which represents the degree of internationalization, are tested in this paper. The estimation results using the SFA technique that incorporates environmental factors are listed in Table 5. First of all, the results show that the likelihood ratio (LR) test of the one-sided error was 21.55 for the entire sample and 37.06 for the IC sub-sample. Second, the estimates of σ^2 were significant for

both equations estimated. The ML estimate for γ was 0.9999 with t-values of 476.75 and 14964.1 for the two equations, respectively. These results are consistent with the conclusion that the true γ -value is greater than zero. Third, it was noted that the estimate for the variable of firm size in the model for the inefficiency effects was negative (although it was insignificant in the IC equation), which implies that larger firms tended to have smaller technical inefficiency in their R&D activities. Fourth, it was also noted that the estimation results in relation to the variable for the share of foreign capital were negative. This might imply that many environmental factors are unfavorable to the R&D efficiency in the sample firms. After these factors are considered in the evaluation, the efficiency scores are seen to improve.

CONCLUDING REMARKS

Results show that possibility of substitution between R&D input factors is slim. High efficiency levels are achieved in most firms when environmental factors are taken into account. The results provide useful information for policy making of the R&D decisions.

Table 5 Estimation Results of R&D Stochastic Frontiers with Environmental Factors

External Variable	Output Variable: Ln of Output Indicator Entire Sample	 IC Sub-sample
Intercept	2.50297 (2.5021)**	9.53681 (2.9781)***
Input Terms:		
LnRDMP	-1.17405 (-2.3163)**	-1.8580 (-4.6571)***
LnRDKS	1.73377 (7.3780)***	0.61684 (1.3304)
$(LnRDMP)^2$	0.10713 (1.8305)*	0.12836 (4.4186)***
$(LnRDKS)^2$	-0.05108 (-2.9473)***	-0.00518 (-0.2498)
(LnRDMP)x(LnRDKS)	0.02953 (0.5198)	0.05626 (1.7639)*
Environmental Factors:		
Number of Employees	-0.40498 (-6.9756)***	-0.21403 (-0.9999)
Share of Foreign Capital	-0.00205 (-0.2611)	-0.05310 (-2.4050)***
σ^2	0.55077 (8.4059)***	0.86404 (3.3394)***
γ	0.99999 (476.75)***	0.99999 (14964.1)***
No. of observations	124	72
Log likelihood function	-122.09412	-51.8478
No. of iterations	15	57
LR test of the one-sided error	21.5531***	37.0600***

Notes: 1. Estimated by Technical Efficiency Effects Model of Battese and Coelli (1995). 2. t-values are in parentheses. 3. The statistics of the LR test for the one-sided error has a mixed χ^2 distribution. The critical value for the mixed- χ^2 distribution with 4 restrictions is 12.483 at the 1% level.

REFERENCES

(omitted)