MALMQUIST INDICES OF R&D PRODUCTIVITY GROWTH IN TAIWANESE IC-DESIGN INDUSTRY

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ABSTRACT

This article employs the Malmquist index, a data envelopment analysis-type nonparametric technique, to decompose productivity growth into technical efficiency and technological change for Taiwanese IC-design firms. The results indicate that the increase in R&D productivity is mainly attributed to the increase in technical change, and the efficiency gain found is largely the result of improvements in scale efficiency. R&D productivity growth from the panel Tobit regression empirically shows that productivity growth did occur due to an increase in the debt ratio, to the firm being small, as well as due to the firm's superior credit rating.

JEL : C61, L63, O30

KEYWORDS: Malmquist index, Productivity growth, Technological Efficiency

INTRODUCTION

The IC-design industry in Taiwan recorded sales of 323 billion NT dollars in 2006, which accounted for 32.2% of the whole of the IC industry's production value. IC-design firms represent one of the most important component producers in the high-tech manufacturing industry worldwide. An effective R&D operation is a major source of competitive advantage in Taiwan's IC-design industry. In the interests of accountability, it is essential to measure the R&D productivity of the firms. Griliches (1994) presents a 'knowledge production function', which views R&D activity as a production process under different parameter methods. The quantitative method begins to analyze R&D efficiency and productivity. However, R&D activity involves multiple inputs and multiple outputs, which makes it problematic to analyze using standard parametric methods. Nonparametric linear programming suits the characteristics of R&D activities much better, but few studies have used Malmquist indices to evaluate R&D productivity growth.

The purpose of this paper is to measure the R&D productivity of Taiwanese IC-design firms and to examine how R&D productivity at the firm level has changed over time. Fundamentally, the evidence presented using either the partial productivity or total factor productivity indices do not tell us anything about the dynamics of the microstructure and the spread of the productivity growth rate within the industry. The Malmquist productivity index we employ can provide additional insights since it can be decomposed into two additional components, one of which measures the change in technical efficiency (i.e., whether firms are getting closer to the production frontier over time), and one which measures changes in technology (i.e., whether the production frontier is moving outwards over time).

By comparing annual changes in the productivity, efficiency and technological change of individual IC design firms, it is possible to both identify general trends in the productivity of the IC-design sector as a whole, and to identify those firms exhibiting patterns of change in productivity. An important task that arises after the calculation of the Malmquist productivity indices is to attribute variation in productivity to the specific characteristics of the firms and the environment in which they operate. A careful analysis of the results should add to our knowledge regarding the factors determining the pattern of IC design firm productivity in Taiwan and provide at least some idea of the effectiveness of microeconomic reform.

This paper gives rise to the following results. First, there is a mean increase in total factor productivity of 21.2% for the period from 2002 to 2006. An examination of the components of the Malmquist TFP index for IC-design firms shows that productivity increase is mainly attributed to the increase in technical change. Technological change plays an important role in TFP growth. Second, in decomposing the components of efficiency change into pure technical efficiency and scale efficiency, we find that scale efficiency is more important in terms of the increase in efficiency. Third, the study shows which determinants are important in order for firms to increase their TFP. As the results of the panel Tobit regression indicate, firm size and TFP are found to be negatively correlated. The firm's credit rating also has a significant negative impact on TFP, whereas a lower debt ratio tends to lead to a higher TFP.

The remainder of the paper is organized as follows. The literature regarding the productivity of R&D activity is reviewed in Section 2. Section 3 provides a brief outline of the Malmquist productivity index. The data used in the present study are described in Section 4. Section 5 presents the empirical results, and Section 5 provides a discussion and conclusions.

LITERATURE REVIEW

The data envelopment analysis (DEA) and Malmquist index methodology usually investigates efficiency change at both firm and country levels. The nonparametric Malmquist index decomposes productivity change into technical change and technical efficiency change. This approach has been applied by many studiies. In the manufacturing industry, related studies include Färe et al. (1992), Hjalmarsson and Veiderpass (1992), Price and Weyman-Jones (1996), Tan (2006), Hashimoto and Haneda (2008), and Liu and Wang (2008). Relevant literature in the banking and financial services sector includes Berg et al. (1992), Gilbert and Wilson (1998), Rebelo and Mendes (2000), Alam (2001), Barros et al. (2005), Rezitis (2006), Lin et al., (2007), and Lee et al. (2008). In the higher education sector, studies include Fernando and Cabanda, (2007), Worthington and Lee (2005) and Flegg et al. (2004). Few papers, however, examine the changes in R&D productivity taking place in the IC design industry.

Griliches (1994) has termed the relationship between R&D inputs and outputs as a 'knowledge production function'. However, R&D inputs and outputs are not easy to quantify, and few studies have analyzed R&D efficiency and productivity. Geisler (1995) and Brown and Svenson (1998) list patents as the output, and compare these with R&D expenditure as the input. Kondo (1999) regards R&D expenditure and patent applications as the R&D input and output, respectively, and analyzes the dynamic mechanism of an R&D-patent function within Japanese industry. Hashimoto and Haneda (2008) present a DEA and Malmquist index methodology to measure the R&D efficiency of Japanese pharmaceutical firms and show that the R&D efficiency of the pharmaceutical industry has deteriorated throughout the sample period. Tollman et al. (2004) also find R&D efficiency has been declining in the pharmaceutical industry. Nasierowski and Arcelus (2003) investigate R&D efficiency (in relation to the use of its input/output ratio) and R&D productivity (by considering the contribution of R&D effort to the national economy), and show that most countries are inefficient by measuring the efficiency of 45 national innovation systems (NIS). Honjo and Haneda (1998) apply data envelopment analysis to the data for 14 companies to evaluate R&D efficiency over the 1977-1991 periods. Their study demonstrates the usefulness of DEA in the comparative evaluation of the R&D activities of companies, and their results show that the DEA and Malmquist index method is suitable for studying the R&D productivity issue. Therefore, in our analysis we focus on R&D productivity and assign variations in productivity change to the specific characteristics of IC-design firms.

ECONOMETRIC METHOD

In order to assess the growth in productivity over time, the study employs the nonparametric input-oriented Malmquist productivity index that decomposes productivity change into technical change and technical efficiency change. This approach has been applied by many studies to analyze productivity.

The description below draws primarily upon the work of Färe et al. (1994), Färe et al. (1998) and Coelli et al. (1998). Let us assume that time period t is the base/current period and that period $t+1$ is the future period. The Malmquist index measures total factor productivity (TFP) change between two data points by calculating the ratio of the distances of each data point in relation to a common technology. Following the framework of Coelli et al. (1998), a production frontier representing the efficient level of output (y) that can be produced from a given level of input (x) is constructed, while making the assumption that this frontier can shift over time. The frontier (F) is obtained in the current (t) and future ($t+1$) time periods. If inefficiency is assumed to exist, the relative movement of any given firm over time will depend on both its position relative to the corresponding frontier (technical efficiency) as well as the position of the frontier itself (technical change). When inefficiency is ignored, then productivity growth over time will be unable to distinguish between improvements that arise when a firm catches up to the frontier or those that result from the frontier itself shifting over time. It is possible to employ the input-oriented Malmquist productivity index to decompose the productivity change between the two periods into technical change and technical efficiency change. The input-oriented Malmquist productivity change index is shown as:

$$M_{t+1}^{t}(y_{t+1},x_{t+1},y_t,x_t)=\left[\frac{d_t(y_{t+1},x_{t+1})}{d_t(y_t,x_t)}\cdot\frac{d_{t+1}(y_{t+1},x_{t+1})}{d_{t+1}(y_t,x_t)}\right]^{\frac{1}{2}} \tag{1}$$

where M is the productivity of the most recent production point (x_{t+1},y_{t+1}) (using period $t+1$ technology) relative to the previous production point (x_t,y_t) (using period t technology), and d is the input distance function. A value of M that is greater than unity indicates that there is positive total factor productivity growth between the two periods. Equation (1) also can be written as:

$$M_{t+1}^{t}(y_{t+1},x_{t+1},y_t,x_t)=\frac{d_{t+1}(y_{t+1},x_{t+1})}{d_t(y_t,x_t)}\cdot\left[\frac{d_t(y_{t+1},x_{t+1})}{d_{t+1}(y_{t+1},x_{t+1})}\cdot\frac{d_t(y_t,x_t)}{d_{t+1}(y_t,x_t)}\right]^{\frac{1}{2}} \tag{2}$$

or

$$M=E\times P \tag{3}$$

where

$$E=\frac{d_{t+1}(y_{t+1},x_{t+1})}{d_t(y_t,x_t)} \tag{4}$$

$$P=\left[\frac{d_t(y_{t+1},x_{t+1})}{d_t(y_{t+1},x_{t+1})}\cdot\frac{d_t(y_t,x_t)}{d_{t+1}(y_t,x_t)}\right]^{\frac{1}{2}} \tag{5}$$

Furthermore, M is the product of a change in efficiency E as measured in period ($t+1$) and period t and a measure of technical progress P as measured by shifts in the frontier over the same period.

Färe et al. (1994) suggest that technical efficiency change can be decomposed into scale efficiency and pure technical efficiency components. If the majority of inefficiency is due to the small size of operations, i.e., increasing returns to scale, then the DMU will need to plan for expansion. On the other hand, pure technical inefficiency can usually be addressed in the short term without changing the scale of operations (Avkiran, 2001). Using this approach, it is thus possible to provide four efficiency and productivity indices for each firm and a measure of technical progress over time. These are: (1) technical efficiency change (E) (i.e., relative to a constant returns-to-scale technology); (2) technical change (P); (3) pure technical efficiency change (PT) (i.e., relative to a variable returns-to-scale technology); (4) scale efficiency change (S); and finally total factor productivity change (M).

Once M is calculated, recalling that M indicates the degree of productivity change, if $M > 1$ then a productivity gain will occur, whilst if $M < 1$ a productivity loss will occur. An interpretation of changes in efficiency (E) is that technical efficiency increases (decreases) if and only if E is greater (less) than one. Technical progress (regress) will have occurred if P is greater (less) than one. An assessment can also be made of the major sources of productivity gains/losses by comparing the values of E and P. If $E > P$, then productivity gains are largely the result of improvements in efficiency, whereas if $E < P$ productivity gains are primarily the result of technological progress. In addition, an indication of the major source of efficiency change can be obtained by recalling that technical efficiency (E) is the product of pure technical efficiency (PT) and scale efficiency (S), such that $E = PT \times S$. Thus, if $PT > S$, then the major source of efficiency change is the improvement in pure technical efficiency, whereas if $PT < S$, the major source of efficiency is an improvement in scale efficiency.

After calculating the Malmquist productivity indices, an important task is to attribute variations in productivity growth to specific characteristics of IC-design firms and the environment in which they operate. We use a panel Tobit model to explain the variation. The general form is:

$$M_{it} = X_{it}^{'}\beta + \varepsilon_{it} \quad i = 1,...,28 \quad t = 2003,...,2006 \tag{6}$$

where M_{it} is the Malmquist productivity index, $X_{it}^{'}$ is a $(1 \times K)$ vector of explanatory variables used to interpret productivity in those IC-design firms, β is a vector of parameters to be estimated, and $\varepsilon_{it} \sim N(0, \sigma^2)$.

DATA AND INPUT/OUTPUT SPECIFICATION

The data used in this study consist of annual observations of 28 Taiwan IC-design firms. The time period selected extends from 2002 to 2006. The inputs to innovation production activities are mainly R&D manpower, R&D expenditure, and physical assets. Physical assets are often a proxy for physical resources that support R&D activities and firm size. R&D manpower and R&D expenditures are usually used as standard inputs in the traditional production function context, and are the most crucial elements in promoting technological progress. R&D manpower data is compiled from officially-released data for each firm. R&D expenditures and physical assets are derived from the Taiwan Economic Journal (TEJ) database over the period from 2002 to 2006, and comprise a total of 5 years of data of publicly-traded companies. To increase the comparability and completeness of the sample, firms for which data were missing or unclear are removed from the dataset. Griliches (1990) indicates that the number of patents is probably the most important indicator of research output, related studies include Brown and Svenson (1998) and Hashimoto and Haneda (2008). The number of patents granted comes from WEBPAT. WEBPAT contains much patent information in Taiwan and widely accessible for research on the following website: http: //www.twpat.com/ WEBPAT/ Default. aspx.

The explanatory variables to be included in the panel Tobit regression are also presented in Table 1. These variables are intended to account for the effect of specific characteristics of IC design firms on productivity. All other things being equal, a big firm in terms of the number of its employees will have more resources to engage in R&D activity. In general, this would imply a positive impact on productivity for IC design firms, so that the coefficient of firm size (EMP) might be positive. However, small firms might be more efficient than big ones. The sign of the coefficient between firm size and productivity is unclear. A high debt ratio (DB) means relatively high operational pressure. This would imply a positive coefficient for the results of the panel Tobit regression. A relatively high credit rating should be more disadvantageous when it comes to sourcing external funds from the capital market, for it may give rise to relatively less R&D productivity and less opportunity to adopt new technological innovations. By contrast, a high employee's bonus ($BOUNS$) may serve as a stimulus for R&D manpower to engage in innovation. While Bond et al. (1997) found that investment is sensitive to cash flow or profit, Audretsch and Thurik (1999) extended the model of Bond et al. (1997) and found that the relationship between R&D investment and cash flow is positive in the sample comprising the U.S. and France. For this reason, liquidity or profit seems to increase R&D investment and productivity. In the paper, we include earnings per share (EPS) as a proxy for liquidity and the profit effect in the panel Tobit model. We expect the coefficient between earnings per share and R&D productivity to be positive.

Table 1: Descriptive Statistics

Variable	Mean	Standard Deviation
R&D manpower (RM)	606.8	1043.9
R&D expenditure (RE)	2003440.1	2824862.1
Physical asset ($ASSET$)	24482802.7	48816320.2
Firm size (EMP)	3343.0	4919.8
Debt ratio (DB)	30.9	15.7
Credit rating ($TCRI$)	4.5	1.8
Employee bonus ($BOUNS$)	1506.1	4534.7
Earnings per share (EPS)	2.4	5.0

Note: $BOUNS$ stands for employee bonus in 1000 NT dollars.

EMPIRICAL RESULTS

The descriptive statistics for all of the variables that we used are presented in Table 1. In the previous section, we defined the Malmquist indices of productivity growth relative to a reference technology. Using this method, three primary issues are addressed in our computation of the Malmquist indices of productivity growth over the sample period. The first is the measurement of productivity change over the period. The second involves the decomposition of changes in productivity into what are generally referred to as an efficiency change (a 'catching-up' effect) and a technological change (a 'frontier shift' effect). Then, the efficiency change is further decomposed to identify the main source of improvement, through either enhancements in technical efficiency or increases in scale efficiency.

At first, we begin by looking at the changes in productivity, efficiency, and technology for IC design firms over the period from 2002 to 2006. In Table 2 descriptive statistics of the average indices of total factor productivity growth (M), efficiency change (E) and technological change (P) over the sample period are presented. As indicated, there was a mean increase in total factor productivity of 21.2% over the period from 2002 to 2006. Given that the Malmquist index of productivity change (M) is a multiplicative composite of efficiency (E) and technological change (P), the major cause of productivity improvements can be ascertained by comparing the values of the efficiency change and technological change indexes. An examination of the components of the Malmquist TFP index for IC-design firms shows that the productivity increase is mainly attributed to the increase in technical change. The technical change component of those firms increases more than the efficiency change component throughout the analysis period.

The numbers of firms for each kind of productivity characteristic are detailed in Table 3, which provides a set of productivity indices that included total factor productivity, the main source of productivity change, efficiency change, the main source of efficiency change, and technological change. As we can see, 16.5 firms on average experienced technological progress. However, only 11.5 IC-design firms encountered technological regress over the sample period. Furthermore, 16.5 firms experienced an overall gain in total factor productivity. On average 13.25 firms experienced an increase in efficiency. Once again, the main source of productivity change originated from technological change on average (18.5 firms), whereas the main source of efficiency change was derived from scale efficiency. In sum, technological change plays an important role in TFP growth and scale efficiency is more important for increases in efficiency.

Table 2: Average R&D Productivity over the Sample Periods

DMU No.	*Firm Name*	*E= PTxS*	*P*	*PT*	*S*	*M=ExP*
1	United Microelectronics Corporation, UMC	0.602	1.366	0.536	1.122	0.822
2	Advanced Semiconductor Engineering, Inc.	1	1.342	1	1	1.342
3	Siliconware Precision Industries Co., Ltd.	0.84	1.191	0.854	0.984	1.001
4	Orient Semiconductor Electronics, Ltd.	0.791	1.24	1.121	0.706	0.982
5	Taiwan Semiconductor Manufacturing Co., Ltd.	0.819	1.388	1	0.819	1.136
6	Macronix International Co., Ltd.	0.864	1.345	0.832	1.038	1.162
7	Mosel Vitelic, Inc.	1	1.285	1	1	1.285
8	Winbond Electronics Corp.	0.651	1.409	0.649	1.003	0.917
9	Silicon Integrated Systems Corp.	0.757	1.376	0.839	0.902	1.042
10	Lingsen Precision Industries, Ltd.	0.629	1.325	1	0.629	0.833
11	Realtek Semiconductor Corp	1.141	1.49	1.127	1.012	1.7
12	Via Technologies, Inc.	1	1.47	1	1	1.47
13	Sunplus Technology Co., Ltd.	0.97	1.464	0.976	0.994	1.421
14	Nanya Technology Corporation	0.835	1.279	0.841	0.993	1.068
15	Weltrend Semiconductor,Inc.	1.218	1.441	1.015	1.2	1.755
16	MediaTek Inc.	1.014	1.412	1.013	1.001	1.431
17	Elan Microelectronics Corp	0.781	1.44	0.831	0.94	1.125
18	ITE Tech. Inc	0.697	1.497	1.032	0.675	1.043
19	Novatek Microelectronics Corp.	1.162	1.498	1.077	1.079	1.74
20	Farady Technology Corp.	0.842	1.476	0.869	0.968	1.242
21	Ali Corporation	1.177	1.474	1.256	0.937	1.734
22	Powership Semiconductor Corp.	1.543	1.318	1.252	1.232	2.034
23	Vanguard International Semiconductor Corp. (VIS)	0.413	1.088	0.749	0.551	0.45
24	Etron Technology Inc.	0.926	1.403	0.995	0.931	1.3
25	ProMos Technology	0.766	1.316	0.81	0.945	1.007
26	Princeton Technology Corp.	1.168	1.448	0.842	1.387	1.691
27	Anpec Electronics Corp.	0.642	1.335	0.969	0.663	0.857
28	Holtek Semiconductor Inc.	1.357	1.504	1.227	1.106	2.042
	Mean	0.881	1.376	0.938	0.939	1.212

P is the geometric mean of the technological change index over the 2002-2006 period. E is the geometric mean of the technical efficiency index over the 2002-2006 period. PT and S are the geometric mean of pure technical efficiency and scale efficiency over the 2002-2006 period, respectively. M represents the geometric mean total factor productivity index over the 2002-2006 period.

Table 3: Productivity Characteristics over the Sample Period

Year	**Productivity**		**Main source of productivity change**		**Efficiency change**		**Main source of efficiency change**		**Technological change**	
	Gain	Loss	Efficiency	Technology	Increase	Decrease	Technical	Scale	Progress	Regress
2002/2003	16	12	6	22	11	17	13	12	16	12
2003/2004	18	10	8	20	13	15	15	10	18	10
2004/2005	19	9	8	20	14	14	11	15	16	12
2005/2006	13	15	16	12	15	13	9	16	16	12
Average	16.5	11.5	9.5	18.5	13.25	14.75	12	13.25	16.5	11.5

The first three columns of Table 4 present the estimated coefficients and standard errors for the regression of the TFP indices on the vector of explanatory variables. A test of the null hypothesis that all the slope coefficients are jointly zero is rejected at the 0.05 level using a Wald chi-square statistic. As the panel Tobit regression indicated, there is a significant negative relationship between firm size (EMP) and TFP. Some of the literature on firm growth shows that small firms grow more rapidly than big firms (Hall, 1987; Evans, 1987). Then, small firms may catch up with big firms. It is not surprising to find that small firms have higher TFP. The debt ratio (DB) exhibits a significant positive relationship with TFP. One implication derived from the results is that firms with higher debt ratios may have more operating pressure, for the larger the debt ratio, the more effort they will have to make. In addition, the firm's credit rating has a negative impact on TFP (Jenson, 1986). The result is that a firm with a higher credit rating (a worse credit situation) will tend not to borrow funds from the capital market. In addition, big firms will tend to borrow funds in an imperfect capital market. A firm's credit rating will tend to be mainly attributed to a regression in TFP.

Table 4 Determinants of Productivity Variation

Variable	Coefficient	Std. Error	t-value
Constant	2.6465***	0.6149	4.30
EMP	-0.0001***	0.0000	-2.73
DB	0.0341***	0.0136	2.51
TCRI	-0.3396***	0.1379	-2.46
BOUNS	0.0000	0.0000	0.81
EPS	-0.0417	0.0390	-1.07

The dependent variable in the panel Tobit regression is M_{it} *(TFP). Asterisks *** indicate significance at the 0.01 level.*

CONCLUDING REMARKS

The importance of R&D is widely recognized. Many firms engage in R&D to gain competitiveness in the market through the acquisition of patents. Many studies show that R&D investment affects the firm's value. However, it is certain that there have been few studies that have sought to evaluate firms' R&D efficiency or to investigate R&D productivity itself. In this paper, we introduce Malmquist index analysis to examine the time series change in R&D productivity at the firm level. The Malmquist index can decompose the productivity movement into two parts: movements of the frontier due to changes in the technological capabilities of the firm (technical change) and movements of the firm towards (or further away from) the frontier as it becomes more (less) successful at reducing internal inefficiency. We find that there was productivity growth during the sample period. The productivity growth appears to be largely due to an increase in technological change (a frontier shift effect). On the other hand, decomposing technical efficiency scores into pure technical efficiency and scale efficiency provides guidance as to what can be achieved. The scale efficiency scores are close to those for pure technological efficiency. The majority of inefficient IC design firms are inefficient due to their poor performance in terms of their pure technological efficiency. The results indicate that the low utilization of the inputs appears to be the key problem.

The results of the panel Tobit regression also indicate that a number of variables can help explain the variation in productivity change in the period. The most important factors determining the level of productivity appear to be the firm size, the debt ratio and the firm's credit rating (a proxy for the cost of capital), whereas the employee's bonus appears positive but insignificant in determining productivity growth. The methodology presented in this study, which is able to measure the R&D productivity change over the 2002 to 2006 period, is able to provide useful information on the firm's R&D activity management.

To conclude, our study provides new insights into the R&D efficiency. It will be interesting and useful to extend this research to other R&D intensive industry. What is more, we suggest future research might concentrate on the more complex methodologies for analyzing the topic on different countries. The limitations to our model is sample size, additional research needs to collect more firm-level data. Therefore, this study's results are regard as the first step of policymaking. Further results should need samples that are more detailed, calculations, and judgments.

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