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The Case of Taiwan's Electronics Industry

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Abstract

This paper uses a unique panel data set in electrical and electronic manufacturing covering from 1988-1997 to evaluate the performance resulting from firms' dynamic behavior over time. Our focus is on the effect of R&D effort on labor productivity of firms in the electrical and electronic manufacturing. Using three variables to measure the R&D effort, we find that the R&D effort is an important determinant of a firm's labor productivity. The three variables we use are (i) the number of full-time researchers hired, (ii) the amount of R&D expenditure spent and (iii) the annual new patents obtained.

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1. Introduction

The electrical and electronic industry in Taiwan has been the most dynamic industry in manufacturing in the last decade. The rapid development of electrical and electronic manufacturing in Taiwan comes in the period, when the world has rapid innovations in the information-related technology. As a result, it could be argued that the rapid growth in the electrical and electronic manufacturing in Taiwan, is due to the research and development made by firms in the last decade. The purpose of this paper is to document the evidence to support this argument.

We will use a unique data set in electrical and electronic manufacturing, covering from 1988-1997. This is a survey data, jointly conducted by the Ministry and Economic Affair and the Directorate General of Budget, Accounting and Statistics. The data is good for evaluating the dynamic performance of a firm's behavior over time, as it is a panel data set that traces each firm over the period under survey. Using three variables to measure the R&D effort, we find that R&D effort is an important determinant of a firm's labor productivity. The three variables are (i) the number of full-time researchers hired, (ii) the amount of R&D expenditure spent and (iii) the annual new patents obtained.

The organization of this paper is as follows. The next Section is the theoretical framework and the estimation model. Section 3 describes the sources of data, the way to construct to construct variables and summary statistics of the labor productivity and capital stock per capita between plants making R&D effort and those without. Section 4 reports the empirical estimation of the relationship between R&D effort and labor productivity. Finally, in Section 5, we make conclusions.

2. Theoretical Framework and Estimation Model

2.1 Theoretical Framework

Consider a firm i in a time period t endowed with the following production technology:

$$Y_{it} = F(A_{it},\ K_{it},\ L_{it}), \qquad \textbf{(1)}$$

where Y_{it} is its value added, K_{it} is its capital stock, L_{it} is its labor input and A_{it} is the level of production efficiency. Assume that the production technology is homogenous of degree one with respect to the capital and labor inputs. This property serves to rewrite the technology as:

$$y_{it} = f(A_{it},\ k_{it}), \qquad \textbf{(2)}$$

where y_{it} is the firm i's value added per capita and k_{it} is its capital stock per capita. A firm's value added per capita is also the firm's average productivity of labor. Note that as Y_{it} is homogenous of degree one with respect to K_{it} and L_{it}, it is well-known that marginal product of capital stock (i.e., $\partial F/\partial K$) equals to marginal per capita product of capital stock per capita ($\partial f/\partial k$).

Log-linearizing equation (2) yields:

$$\ln y_{it} = \beta_0 + \beta_1 \ln k_{it} + \gamma \ln A_{it}. \qquad \textbf{(3)}$$

Equation (3) says how the average labor productivity of a firm is determined. It says that, other than idiosyncratic factors of a firm, two most important sources affecting average labor productivity of a firm is its capital stock and the productivity level. In a production function with one degree of homogeneity in capital and labor, capital and labor are in general pareto complementary. A larger stock of capital per capita will raise the average labor productivity. Moreover, other things being equal, the higher the productivity level of a firm, the higher the average labor productivity.

As the input of capital stock which can be directly chosen by a firm, the productivity level can also be chosen by a firm. Existing theoretical works have found that R&D effort is the major vehicle to enhance the level of productivity. See, among others, Reinganum (1985) in the area of industrial organization and Aghion and Howitt (1992) in that of endogenous growth. Denote as s_{it} the level of R&D effort made by a firm *i* in period *t*. Without loss of generality, we can normalize s_{it} so that it also denotes the cost of R&D activities. Then, the level of productivity in period *t* of a firm *i* is a positive function of R&D effort made in period, which can be expressed as:

$$A_{it} = A(s_{it}),\; A^{\prime}>0. \qquad \textbf{(4)}$$

2.2 **Estimation Model**

Equations (3)-(4) are what we want to estimate. Therefore, our model for estimation is:

$$\ln y_{it} = \beta_0 + \beta_1 \ln k_{it} + \alpha X_{it} + \gamma \ln s_{it}, \qquad \textbf{(5)}$$

where X_{it} is a vector of other idiosyncratic factors pertaining to a firm or an industry that the firm belongs to. Several variables of idiosyncratic factors will be controlled. For the R&D effort, several measures will be employed in order to confirm the robustness of estimation results.

3. Data and Descriptive Statistics

3.1 Sources of Data

This paper uses a unique data set of electrical and electronic machinery manufacturing in Taiwan. The data set is unique as it is the only panel data set at a plant level for the manufacturing industry. The Taiwan government (both the Ministry of Economic Affairs and the Directorate General of Budget, Accounting and Statistics jointly) has conducted an industrial and business census at a plant level for every five year since 1956. In the four years between any two consecutive census years, the government has conducted a small scaled survey. Unfortunately, for reasons such as protecting the information of business enterprises, the government statistic bureau releases the census and survey data so that the data users cannot know the plant and cannot trace the same plant. The only exception is the electrical and electronic survey data covering from 1987-1990, 1992-1995 and 1997. This data set is paneled so that a user can trace a plant across years. The data for the year 1991 and 1996 are not available for a panel as only census data are available in these two years. All the plants surveyed in the data set have the number of employees equal to or larger than 30.

In this data set, the R&D related data are surveyed from 1988. There are three kinds of data that can be used to measure a firm's D&D effort. First, whether the firm has hired full-time researchers for doing R&D. Second, whether a firm has R&D expenditure. Finally, whether a firm obtain new patents (either locally or internationally). While the first two measures represent a firm's R&D efforts, the third measure symbolizes the outcome of R&D effort. There is a fourth kind data that can be potentially useful for measuring R&D effort. It is the purchase of technology from either local firms or multinationals. Yet, the number of firm is negligible, making the data an improper measure in estimation. For example, the number of firm purchasing technology in 1988 is 48 which is a very small number compared to those not purchasing technology whose number is 6874. For the three kinds of R&D measures we use, all data are available from 1988 to 1993. After 1993, only the data of R&D expenditure is available.

3.2 Descriptive Statistics

Labor productivity of a firm in a particular year is measured as the value added divided by the number of employees of that firm in that year. The value added of a firm in a particular year is calculated by subtracting from the revenue[1] the operation costs other than wage payments[2] of that firm in that year. The capital stock per capita for a firm in a particular year is calculated by

[1] The revenue includes the sales revenue and the revenue from repairing and subcontracting manufacturing.

[2] Specifically, the operation costs other than wage payment are the costs of material including gasoline, electricity and water, the subcontracting expenditure, and other operational and business expenditure.

dividing the operational fixed asset by the number of employees. For all the data, if a firm has a zero or negative value for either the value added per capita or capital stock per capita, the data is dropped from use. The value added is deflated to the 1988 value by using the whole-sale price index of the electrical and electronic machinery. The capital stock is deflated to the 1988 value by using the whole-sale price index of capital goods. Both price indexes come from *The Commodity Price Statistics Monthly in Taiwan Area of The Republic of China* (Directorate General of Budget, Accounting and Statistics, Dec. 1993 and July 1999).

We are now ready to report summary statistics between firms with R&D efforts and those without. As noted earlier, three measures are used to represent the R&D investment. Table 1 illustrate the summary statistics for firms with and without hiring full-time R&D researchers. The upper panel in this Table is for firms hiring full-time R&D researchers, whereas the lower panel is for those without. The data for hiring R&D researchers is available only until 1993. In 1988, there are 775 firms hiring full-time R&D researchers, and 6147 without. Almost 90 percent of firms in 1988 in our data have hired no full-time R&D researchers. The number of firms hiring full-time R&D researchers has been then increasing both in terms of an absolute number and as a percentage of total firms under concerns. Comparing these two types of firm, it is not surprising to find that the value added per capita for firms which have hired full-time R&D researchers is higher than those without, except for the year 1989. Of course, a larger value added per capita could reflect not only a firm's R&D efforts, but also its larger capital input. Examining the capital stock per capita, it is evident that the firms hiring full-time R&D researchers on average employ a larger stock of capital per capita.

[Insert Table 1 about here]

Table 2 demonstrates summary statistics between firms with and without R&D expenditure. The R&D expenditure have data available for a longer series (until 1997). Again, the number of firms with R&D expenditure is much smaller than that without R&D expenditure. Comparing the number of firms hiring full-time R&D researchers with that making R&D expenditure, the latter number is larger. Its number, however, peaked in 1993 and then decreased. Again, the firms with R&D expenditure on average have a larger value added per capita than those without for every year except for, again, the year 1989. The capital stock per capita is also higher for firms with R&D expenditure.

[Insert Table 2 here]

Finally, Table 3 displays summary statistics for firms with new patents and those without in a particular year. Of the three measures of R&D, the number of firms with new patents is the smallest. The reasons may be that some firms' R&D effort is made mainly for reverse-engineering and adopting and importing technology. Yet, from Table 3, we clearly see that the number of firm obtaining new patents increases over time. Again, the value added per capita for firms obtaining new patents is higher than those not obtaining except for the year 1989. The capital stock per capita for firms with new patent is also larger than those without.

[Insert Table 3 here]

4. Estimation Results

We are now ready to report the results of empirical estimation. As a first step, we pool the plant data in all years available. Although we do not trace a firm in this way, the estimation captures firm dynamic behavior as the outcomes resulting from firm dynamic behavior are used in the estimation.

We begin by illustrating the estimation pooling data in 1988-1993. Table 4 reports the estimation results. The dependent variable is the logarithmic real value added per capita of a firm. The two major determinants of the labor productivity are real capital stock per capita ($Log(K/L)_t$) and the R&D effort. While columns (1) and (2) use full-time researchers as a measure of R&D efforts , columns (3)-(4) and (5)-(6) use R&D expenditure and new patents, respectively. When full-time researchers and new patents are employed, a dummy variable is entered in the regression to capture whether a firm has hired full-time researchers ($RESEARCHERD_t$) or has obtained new patents ($PATENTS_t$). When R&D expenditure is used, we enter the variable with its logarithmic value ($Log(R\&DEXP_t)$).[3] All the columns control for the age of a firm (*AGE*)and also control a time dummy (*YEAR*). A age square term(AGE^2) is also controlled in some estimation equations to see whether the labor productivity of a younger and an older firm differs. The estimation results and the *t* values show that all the estimated coefficients are statistically significant at the 1 percent level.

[Insert Table 4 here]

From the estimated results, it is clear to see that the estimated coefficients of logarithmic value of capital stock per capita ($Log(K/L)_t$) are all positive as anticipated and are all statistically significant at the 1 percent level. The magnitude of estimated coefficient of capital stock per capita is smaller than 1/3 that is thought to be the share of capital stock in production. All the estimated coefficients of the year dummy variables (*YEARD*) are positive and statistically

[3] When the original value of R&D expenditure is 0, we assign the value 0 for its logarithmic value.

significant, indicating the increasing trend of labor productivity over time. The estimated coefficients of the age dummy of a firm (*AGE*) are positive and statistically significant at the 1 percent level, showing that an older firm a larger labor productivity, other things equal. Yet, the marginal contribution of the age of a firm to its labor productivity statistically and significantly decreases over time as seen by the estimated coefficients of AGE^2.

For the three measures of R&D effort, the estimated results in columns (1)-(2) indicate that a firm whish has hired full-time researchers has a larger labor productivity. The estimated coefficients suggest that the labor productivity is increased by 0.277 (at the logarithmic scale), or by 114.78 thousand New Taiwan Dollars (NT$) if we evaluate the impact at the sample mean of the real value added per capita.[4] This is a large effect. The results in column (3)-(4) also show that the R&D expenditure positively and statistically significantly enhances labor productivity. Finally, the estimated coefficients in columns (5)-(6) using new patents as a measure of R&D efforts are positive and statistically significant. This outcomes mean that a firm which obtains new patents due to its R&D effort has a higher labor productivity.

The data for the R&D expenditure has a longer series which is available until 1997. For further evidence, we also estimate equation (5) by polling all the plant level data between 1988 and 1997. The estimated results are reported in Table 2. Column (1) in the Table does not control for the variable AGE^2, column (2) does. As the estimated outcomes in these two columns show, the results are the same as those in Table 4.

[Insert Table 3 here]

[4] The sample mean for the real value added per capita is 414.38 thousand NT$..

5. Concluding Remarks

This paper uses a unique panel data set in electrical and electronic manufacturing covering from 1988-1997 to evaluate the performance resulting from firms' dynamic behavior over time. Our focus is on the effect of R&D effort on labor productivity of firms in the electrical and electronic manufacturing. Using three variables to measure the R&D effort, we find that the R&D effort is an important determinant of a firm's labor productivity. .The three variables are (i) the number of full-time researchers hired, (ii) the amount of R&D expenditure spent and (iii) the annual new patents obtained. Firms with R&D effort are found to have higher labor productivity.

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Table 1. R&D Researchers

(1000 NT$)

years		1988	1989	1990	1992	1993
Firms with Full-Time R&D Researchers	No. of Firms	775	869	979	1300	1447
	Capital Stock per Capita	557.8	602.8	732.2	987.0	1034.9
	Value Added	418.5	441.2	505.9	661.4	654.6
Firms without Full-Time R&D Researchers	No. of Firms	6147	6242	6158	6425	6220
	Capital Stock per Capita	460.3	499.0	536.4	718.6	815.3
	Value Added	300.2	449.7	325.3	452.8	414.5

Table 2. R&D Expenditure

(1000 NT$)

years		1988	1989	1990	1992	1993	1994	1995	1997
Firms with R&D Expenditure	No. of Firms	1123	1218	1438	1689	1816	1718	1598	1607
	Capital Stock per Capita	534.4	590.3	687.4	904.3	967.4	1083.1	1010.2	1576.8
	Value Added	398.9	419.9	471.9	623.8	610.5	746.3	845.4	896.7
Firms without R&D Expenditure	No. of Firms	5799	5993	5699	6036	6251	6615	7066	7666
	Capital Stock per Capita	458.9	495.4	531.8	724.4	821.9	836.1	1019.7	1154.8
	Value Added	297.0	454.3	319.2	449.9	413.1	478.2	540.8	528.7

Table 3. New Patents

(1000 NT$)

years		1988	1989	1990	1992	1993
Firms with New Patent	No. of Firms	205	185	295	423	373
	Capital Stock per Capita	467.3	536.0	682.42	859.5	851.0
	Value Added	378	380.1	407.6	655.2	639.2
Firms without new Patent	No. of Firms	6717	6926	6842	7302	7694
	Capital Stock per Capita	471.3	519.52	554.7	758.23	854.9
	Value Added	311.5	450.5	340.4	478.26	448.7

Table 4. Estimation Results, 1988-1993

	(1)	(2)	(3)	(4)	(5)	(6)
INTERCEPT	-0.4763***	-0.4652***	-0.5070***	-0.4961***	-0.6939***	-6.830***
	(2.913)	(2.845)	(3.110)	(3.044)	(4.214)	(4.149)
Log (K/L)$_t$	0.1607***	0.1604***	0.1580***	0.1577***	0.1692***	0.1690***
	(55.402)	(55.323)	(54.482)	(54.485)	(58.284)	(58.207)
YEARD	0.0644***	0.0641***	0.0649***	0.0646***	0.0670***	0.0667***
	(30.983)	(30.845)	(31.295)	(31.159)	(31.998)	(31.862)
AGE	0.0060***	0.0110***	0.0055***	0.0104***	0.0670**	0.0115***
	(8.338)	(9.302)	(7.698)	(8.870)	(31.998)	(9.716)
AGE^2	--	-0.0229***	--	-0.0225***	--	-0.0226***
		(5.343)		(5.285)		(5.241)
RESEARCHERD$_t$	0.2774***	0.2776***	--	--	--	--
	(25.35)	(25.371)				
Log (R & D EXP)$_t$	--	--	0.0358***	0.0357***	--	--
			(28.972)	(28.978)		
PATENTS$_t$	--	--	--	--	0.0106***	0.0106***
					(5.836)	(5.825)
No. of Observations	36849	36849	36849	36849	36849	36849
adj R^2	0.1445	0.1452	0.1490	0.1496	0.1304	0.1331

Note: The estimation is conducted by pooling the plant-level data from 1988-1993. The *t* values are in parentheses. The notation *** indicates the statistical significance at the 1% level.

Table 5. Estimation Results, 1988-1997

	(1)	(2)
INTERCEPT	-0.0568	-0.0527
	(0.679)	(0.630)
Log (K/L)$_t$	0.1533***	0.1532***
	(64.117)	(64.09)
YEARD	0.0595***	0.0594***
	(56.534)	(56.353)
AGE	0.0029***	0.0064***
	(5.264)	(6.683)
AGE^2	--	-0.0154***
		(4.456)
Log (R & D EXP)$_t$	0.0419***	0.0419***
	(41.777)	(41.769)
No. of Observations	54670	54670
adj R^2	0.187	0.187

Note: The estimation is conducted by pooling the plant-level data from 1988-1997. The *t* values are in parentheses. The notation *** indicates the statistical significance at the 1% level.