



R&D EXPENDITURE, SPILLOVERS AND PRODUCTIVITY-EMPIRICAL STUDY OF TAIWANESE OPTOELECTRONIC INDUSTRY



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ABSTRACT

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In prior research on the productivity of Taiwanese optoelectronic industry as determined by panel data, the Cobb-Douglas production function and R&D spillovers are rarely discussed. Therefore, this paper examined the effects of R&D expenditure and R&D spillovers on productivity in the Taiwanese optoelectronic industry to explore. This paper constructed firm-level panel data of the Taiwanese optoelectronic industry from 2000 to 2018, and used Griliches and Mairesse (1979) extended Cobb-Douglas production function for our empirical framework. Then we chose the fit fixed effect or random effect model for our panel data by testing the empirical model. Besides the full-sample analysis, this paper divided our sample into the four sub-samples of optoelectronic information, display, component and communication to detect the difference from each group on productivity. The empirical results suggested that for both the total sample and the sub-samples of the optoelectronic industry, R&D expenditure and R&D spillover effects have positive contributions to productivity. Although Taiwan's optoelectronic industry has considerable assembly application capabilities and a complete background of related industries, the mastering of core technology and the development of key components still need to be strengthened. Based on strong photo-electronics, information and manufacturing capacities, an in-depth study should be carried out by integrating these different fields and focusing on intellectual properties to create applications with high added value, high precision and a high price through R&D innovations. In this way, Taiwan manufacturers can contribute to the market and promote overall social and economic development.

Contribution/ Originality: This study is one of few that have investigated this issue in newly industrialized economies (NIEs), and the results based on Taiwan's experience could serve as a valuable reference for other developing countries.

1. INTRODUCTION

Photovoltaics is a fast-growing market. The compound annual growth rate (CAGR) of photovoltaic installations was 24% from the year 2010 to 2017 (ISE, Fraunhofer Institute for Solar Energy Systems, 2019 report). In terms of 2017 PV module production, China and Taiwan held the lead with a share of 70%, followed by the rest of the Asia-Pacific and Central Asia (ROAP/CA) with 14.8% (ISE, 2019 report). Europe contributed a share of 3.1% (compared to 4% in 2016) while the USA/CAN contributed 3.7% (ISE, 2019 report).

According to statistics from the Photonics Industry & Technology Development Association (PIDA), the optoelectronic industry in Taiwan has been gradually growing since 2000 and has become a pillar of the economy, second only to the semiconductor industry (PIDA report). In 2018, the output value of Taiwan's precision optical components was NT\$101.4 billion (PIDA report). It is estimated that there will still be opportunities to grow in 2019, with an output value of about 106.8 billion yuan, an annual increase of 5% (PIDA report).

Since the optoelectronic industry is a high-tech industry requiring high capital, knowledge value and technical value, like the semiconductor industry, its growth trend and demands are not necessarily the same as those for the electronics industries of the past. As the optoelectronic industry has been in a growth stage in recent years but there are no ample and long-term empirical data available, it is necessary and of academic value to study its development.

Financial crises result in global economic downturns, and there are few industries that can escape this wave of economic depression. Historical experience of Ford's innovative production management suggests that only value creations, such as innovative administration, creative technologies and applications, can resist the trend of prices falling (Ford website-Experience a transformative innovation's history). The production cost reductions and innovative applications caused by technological innovations, the introduction of new technology and the vertical integration of upstream and downstream businesses can be regarded as the ultimate reflection of the research and development (R&D) investment or expenditure concepts in production revenue.

Past academic literature has argued that R&D expenditure, productivity and business revenue have a positive correlation. For example, Griliches (1986) found that R&D activities have a positive impact on a company's productivity. The research findings of Chuang and Hsu (1999) suggested that industries with higher R&D expenditures significantly contribute to productivity. Yang and Chen (2002) indicated that knowledge stock has a significant impact on company sales and added value, whether it is measured by the R&D capital from the investment perspective or the patent capital from the output perspective.

In the mid-1980s, Romer (1986) and Lucas (1988) proposed the endogenous growth theory using human capital accumulation for the research and development of other mechanisms to avoid declining capital marginal productivity and solve the problem of real per person income stagnation in the exogenous growth model proposed by Solow (1956). The innovations brought about by products and manufacturing processes through investment in R&D can help increase productivity and efficiency. In addition to its productive nature, R&D investment can be viewed as a capital stock. More importantly, R&D has externality. Through the trading of intermediate goods and investment capital, the diffusion of technological knowledge and direct foreign investment in Taiwanese products and manufacturing technology, the industry's technology can be upgraded and productivity can be increased.

These are known as the R&D spillover effects. As the empirical results of the above mentioned literature suggest, most of the returns for many enterprises come from the R&D spillover effects. For example, Terleckskyj (1974;1982) found that the return brought by the R&D spillover effects is about 45%, as compared with a return rate of 28% from direct engagement in R&D. Nadiri and Wolff (1987) also stated that the inter-industry R&D spillover rewards are far greater than an individual company's R&D investments. In addition, the research by Goto and Suzuki (1989) using the Japanese manufacturing industry as the sample, confirmed that the return on investment of individual industries receiving external R&D capital is about three times more than the industry's own R&D capital investment.

Most literature on the optoelectronic industry has focused on analyzing operational efficiency. For example, Lee and Chen (2008) employed the data envelopment analysis method and the Maxwell productivity change index analysis method to compare the business operational efficiency and productivity changes of CD-ROM, CD-ROM drive and LED manufacturers in the optoelectronic industry from 2003 to 2005 and assess the major factors and the level of impact on the production efficiency of the optoelectronic industry in Taiwan.

Since empirical studies on the optoelectronic industry's productivity using panel data and Cobb-Douglas production function are rare, and because there has been no in-depth exploration of R&D spillovers in past literature,¹ this study discussed whether R&D expenditures and the industrial R&D spillover effects would affect the productivity of manufacturers in the optoelectronic industry.

This study constructed firm-level panel data of Taiwan's optoelectronic industry from 2000 to 2018 and adopted the expansionary Cobb-Douglas production function proposed by Griliches and Mairesse (1979) as the empirical structure. The testing method of the panel data's fixed effect or random effect was used to select the most appropriate empirical model. In addition to full-sample empirical analysis, the samples were categorized into groups to determine whether productivity would vary in the optoelectronic information, display, components and communications sub-industries of the Taiwanese optoelectronic industry.

2. LITERATURE REVIEW

2.1. Literature Relating to R&D Expenditure and R&D Spillovers

Evenson and Kislev (1973) and Griliches and Mairesse (1979) were the first to study the R&D spillover effects, arguing that the enhancement of the spillover effects will promote R&D investment. Griliches and Mairesse (1979) pointed out that R&D spillover is a type of externality and the source of industrial "endogenous technological change". The spillover effects will occur if there is a correlation between industries or firms.

The empirical research has pointed out that most of the rewards of many companies come from the spillover effects of R&D. For example, Terleckskyj (1974;1982), Nadiri and Wolff (1987) and Goto and Suzuki (1989) all confirmed that the spillover effects of investment in R&D are an important factor in business growth.

Jaffe (1986) argued that R&D activities have spillover and competitive effects. Therefore, the empirical impact of the spillover indicators on business performance should be subject to the R&D spillover and competitive effects. Bernstein and Nadiri (1988) also pointed out that R&D spillover exists in various industries, and that the level of spillover effects varies according to the industrial nature. In particular, high-tech industrial spillover effects will be more significant.

Bernstein (1989) argued that the R&D spillover effects are the autonomous technical progress of the receiving industries caused by the R&D activities and knowledge capital stock of an industry. Goto and Suzuki (1989) defined the R&D spillover effects as the marginal productivity improvement of other industries caused by the diffusion of technological knowledge.

Recent scholars of endogenous growth theory (Romer, 1986;1990a;1990b; Grossman and Helpman, 1991; Aghion and Howitt, 1992) have all underlined R&D's externality. Through the spillover effects of technical knowhow, the accumulation of knowledge and the reduction of innovation costs can result in relative improvements in the marginal rewards of individual R&D activities and promote continuous economic growth. Goto and Suzuki (1989) indicated that the impact of industrial R&D on the productivity of another industry can be realized by technical staff turnovers or academic journals, in addition to the trading of intermediate goods and investment capital, of which the latter is the diffusion of new technological knowledge. Suzuki (1993) using the vertical integration of upper, middle and downstream firms in the Japanese electronics industry as the research subject, found that the spillover effects of integration can reduce production change costs, in addition to the technical transfer effect of the integration of upper and downstream companies. This is also the reason for Japan's automobile and electronics industries' continued competitiveness. It thus can be seen that in high-tech industries, vertical integration does have spillover effects.

Regarding Taiwanese literature on R&D spillover effects, Chuang and Hsu (1999) using Taiwan's manufacturing industry as the research sample, pointed out that a significant R&D spillover effects exists in

¹Regarding the empirical research on Taiwan's photonics industry, please refer to Chang (2005).

industries with both high and low R&D intensity, and that the spillover effects for industries with high R&D intensity is more significant. [Chen \(2002\)](#) employed the Cobb-Douglas production function to analyze the impact of R&D and its spillover effects on productivity changes. The empirical results suggested that the R&D spillover effects can help considerably improve productivity. The research findings suggested that rising R&D capital stock has a positive and significant impact on productivity growth. This can be an incentive for firms to actively invest in R&D. [Chu \(2007\)](#) used the vertical and horizontal threshold production function to analyze the R&D spillover effects of 333 Taiwanese publicly listed companies in the information electronics industry during 2002-2005. The empirical results suggested that R&D stock and R&D spillover are in a complementary relationship, which may not vary according to the R&D stock.

[Tsai \(2008\)](#) reviewed the empirical studies on Taiwan's high-tech industrial development and relevant issues. The direct contribution of R&D to output growth is not great. However, the inter-industry and intra-industry R&D spillover effects have a significant impact on output growth. The clustering effect of high-tech industries has a positive impact on the spillover effects, learning effect and vertical division of labor system of high-tech industries. R&D, information technology, electronic systems and their spillover effects have significant and positive contributions to the technical progress and development of high-tech industries. [Fuglie \(2018\)](#) found that developed countries appear to have benefitted more from private and international R&D spillovers than developing countries.

Through analysis of the literature, it can be clearly found that R&D expenditures and R&D spillover have significant and positive contributions to the productivity of high-tech industries. Most of the past literature has adopted the Cobb-Douglas production function to construct empirical models using the total output of added value. However, the optoelectronic industry is an industry with high capital and high technicality. Whether R&D expenditures and R&D spillover have a significant and positive impact on the productivity of the optoelectronic industry, and whether R&D investment or intra-industry R&D competition can improve the productivity of the optoelectronic industry are issues of tremendous academic and practical value. Similar studies on these issues in newly industrialized economies (NIEs) have been rare and the results based on Taiwan's experience could serve as a valuable reference for other developing countries.

3. EMPIRICAL FRAMEWORKS

3.1. Cobb-Douglas Production Function Model

Literature on the relationship between R&D expenditures and productivity generally uses the Cobb-Douglas production function for estimation. In addition to the traditional production investment factors such as capital and labor, this study integrated considerations of R&D and R&D spillover ([Terleckskyj, 1974;1982; Scherer, 1982; Nadiri and Wolff, 1987; Goto and Suzuki, 1989; Liu et al., 2013; Li and Bosworth, 2018](#)). It was assumed that the production function of manufacturers in the optoelectronic industry could be approximated by the Cobb-Douglas model as can be seen in [Equation 1](#):

$$Y_{it} = A_{it} e^{\lambda t} CAP_{it}^{\alpha} LAB_{it}^{\beta} RDI_{it}^{\gamma} RDS_{it}^{\eta} e^{\varepsilon_{it}} \quad (1)$$

where Y is the output, CAP stands for capital, LAB represents the number of employees, RDI is the R&D expenditure, RDS is the R&D spillover, i , t and λ stand for the manufacturer, the year and external technical change rate that has not been considered, and ε is the error reflecting other unknown variables and fluctuation effects. A linear regression model can be obtained by taking the logarithm of [Equation 1](#) then we can get [Equation 2](#):

$$y_{it} = a + \lambda_t + \alpha cap_{it} + \beta lab_{it} + \gamma rdi_{it} + \eta rds_{it} + \varepsilon_{it} \quad (2)$$

where y , cap , lab , rdi and rds stand for the logarithms of the output, capital, labor, R&D expenditure and R&D spillover, respectively, and α , β , γ and η are the flexibility of labor, capital, R&D expenditure and the R&D spillover against output.

3.2. Panel Data Empirical Model

This paper integrated time-series and cross-sectional data, namely, panel data. In the measurement of cross-sectional and time-series data, the OLS (ordinary least squares estimation) analysis is usually applied. However, the OLS is prone to bias. In cases of data with a heterogeneous nature, the estimated results using traditional OLS may have differences between the overall and individual data analysis results. Hence, to reduce inter-bank heterogeneity problems, this study adopted the fixed effect and random effect model to replace the traditionally used OLS method.

The consideration of time-series data or cross-sectional data only may result in low freedom caused by insufficient samples. The adoption of panel data can effectively strengthen the analysis capabilities of the model and reduce estimation bias. The consideration of time-series data only may result in an insufficient explanatory power for the model. The consideration of cross-sectional data only may result in the collinearity problem of variables. The results of the F-test and the LM test can determine the appropriate mode for the panel data.²

3.2.1. Fixed Effect Model

Also known as LSDV (least square dummy variable model), the fixed effect model assumes that the intercept of each manufacturer does not change with time. However, different specific constants lie between manufacturers, and the different structures of various manufacturers are represented by fixed intercepts. The model assumes the similarity inside the population is low, and that samples are not obtained by sampling. Instead, the sample population is used to discuss the differences between manufacturers. If there are i manufacturers facing t periods of panel data, then the regression equation would be Equation 3:

$$Y_{it} = \beta_{li} + \sum_{k=2}^K \beta_k X_{kit} + \varepsilon_{it} \quad (3)$$

where, i denotes manufacturers, $i=1, \dots, N$, and t denotes time unit, $t=1, \dots, T$. The selection of the fixed effect model and least square method estimation equation should test whether the intercept of the fixed effect model remains unchanged in various manufacturers. The F test model was used for testing in this paper.

(a) Establish hypothesis

H_0 : $\beta_{11} = \beta_{12} = \dots = \beta_{1N}$, apply the least squares method. H_1 : β_{ij} are not fully equal, apply the fixed effect model.

(b) Model test: use the F distribution to determine whether there is a fixed effect.

$$F = \frac{(SSE_R - SSE_U)/(N-1)}{SSE_U/(NT - N - K)}$$

If the testing results reject H_0 , then apply the fixed effect model. If it does not reject H_0 , apply the least square method for estimation.

² Regarding empirical studies on fixed and random effect models, please refer to literature by Lee (2004).

3.2.2. Random Effect Model

The random effect model is also known as the error components model. Both the fixed effect and random effect models tolerate cross-sectional or vertical-sectional differences. The fixed effect model measures the differences between the population and a vertical section by integrating the dummy variables. The random effect model takes consideration of the random changes of the intercepts, allowing the model to reflect cross-sectional and vertical-sectional differences. If an intercept is a random variable that does not change with time, the model underlines the overall relationship of the data rather than the differences between individual manufacturers. Hence, samples are not taken randomly from the population. If the intercept is randomly produced, then the regression equation is Equation 4:

$$Y_{it} = \sum_{k=1}^K \beta_k X_{kit} + \mu_i + \varepsilon_{it} \quad (4)$$

where, μ_i is the random variable. The selection of the random effect model and the least square method estimation equation should test the existence of random intercepts in the random effect model using the Lagrange multiplier test (LM) proposed by Breusch and Pagan (1980).

(a) Establish hypothesis

$H_0: \sigma_\mu^2 = 0$, apply the least squares method. $H_1: \sigma_\mu^2 \neq 0$, apply the random effect model.

(b) Model test: the LM testing method is used to determine the existence of random intercepts.

$$LM = \frac{NT}{2(T-1)} \left[\frac{\mathbf{e}'(\mathbf{I}_N \otimes \mathbf{J}_T)\mathbf{e}}{\mathbf{e}'\mathbf{e}} - 1 \right]^2 \sim \chi_{(1)}^2$$

If the testing results reject H_0 , then apply the random effect model. If H_0 is not rejected, then apply the least squares method for estimation.

3.2.3. Hausman Test

If the testing results of the fixed effect model or the random effect models are better than the least square method, the selection of the fixed effect model or the random effect model can be determined by the testing method, as proposed by Hausman (1978). However, the estimation by the random effect model would not be consistent, therefore, the fixed effect model would be better than the random effect model in this case. On the contrary, when the intercept and explanatory variable are not correlated, the random effect model will be better than the fixed effect model.

(a) Establish hypothesis

H_0 : the random effect estimation equation will be effective and consistent, but the fixed effect estimation will be invalid. H_1 : the random effect estimation equation will not be consistent and the fixed effect equations will be consistent and valid.

(b) Model test: use the chi-square distribution test to determine which model will be used.

$$H = (\hat{\beta}_{\text{fixed}} - \hat{\beta}_{\text{random}})' \left[A \text{var}(\hat{\beta}_{\text{fixed}}) - A \text{var}(\hat{\beta}_{\text{random}}) \right]^{-1} (\hat{\beta}_{\text{fixed}} - \hat{\beta}_{\text{random}})$$

In the above equation, $\hat{\beta}_{\text{fixed}}$ is the estimation equation of the fixed effect model, $\hat{\beta}_{\text{random}}$ is the random effect estimation, and A is the average value. If the testing results reject H_0 , then apply the fixed effect model. If the testing results do not reject H_0 , then apply the random effect model.

3.3. Data Sources

This paper conducted an empirical study of the data, from the first season in 2000 to the fourth season in 2018, of 133 Taiwanese publicly listed companies. The company data source was the TEJ (Taiwan Economics Journal) company's databank. The companies were classified according to PIDA by industrial scale and product property, and the optoelectronic industry was sub-divided into five sub-categories, including the optical information, optical display, photo-electronics component, optical communications and the entire optoelectronic industry.

3.4. Variable Description

The variables used in the study are described as follows. The total output (Y) is the net business revenue. The capital (CAP) is the sum of the land costs, building costs, machinery and equipment costs and the cost of other facilities. Labor (LAB) is the number of employees. R&D expenditure (RDI) is the R&D costs of the business center. R&D spillover (RDS) is the proportion of i company's R&D expenditures against the sum of R&D expenditure sub-samples. The basic statistics of the variables are as shown in Table 1.

The annual total output (Y) of the total sample of the optoelectronic industry is about 3.5 billion NTD on average (see Table 1). The optical display and optical communication sub-samples are both above the industrial average (see Table 1). The annual capital (CAP) of the total sample of the optoelectronic industry is 6.2 billion NTD on average (see Table 1). The annual capital of the optical display sub-sample (CAP) is about 18.5 billion NTD on average, indicating the optical display manufacturers should invest a large sum of capital in fixed assets (see Table 1). The annual labor (LAB) of the total sample of the optoelectronic industry is about 973 employees on average, and the annual number of employees of the optical display sub-sample is about 2008 people, indicating that the optical display manufacturers have a great demand for employees in addition to a large investment in fixed assets (see Table 1).

The annual R&D expenditure (RDI) of the total sample of the optoelectronic industry is about 80,000,000 NTD on average, and the annual R&D expenditure of the optical display sub-sample is about 0.15 billion NTD on average, indicating that the investment in R&D by the sub-sample is higher than the industrial average, in addition to large investments in fixed assets and labor (see Table 1). The R&D investment of the optical communication sub-sample is also higher than the average of the optoelectronic industry (see Table 1). The annual R&D spillover (RDS) of the total sample of the optoelectronic industry is 0.00028% on average, and the average annual R&D spillover of the optical communication subsample, at 0.0015%, is the highest followed by the average annual value of the optical display sub-sample, at 0.0011% (see Table 1).

4. EMPIRICAL RESULTS

4.1. Testing of the Empirical Model

This study categorized the samples into five sub-samples, including optical information, optical display, photo-electronics components, and optical communication. The F-test, LM-test and Hausman test were applied to various sub-samples and the total sample to select the most suitable empirical model of panel data. The testing of the most suitable empirical model in this study was as shown in Table 2. The models of optical information, optical display,

photo-electronics components, optical communication and the optoelectronic industry were the panel data models suitable for the fixed effect.

4.2. Empirical Analysis

The empirical results of the total sample of the optoelectronic industry, are shown in Table 3. The elasticity of R&D expenditure was 0.06, indicating that every 1% increase in R&D expenditure can result in a 0.06% unit of productivity increase. The elasticity of R&D spillover was 0.075, indicating that every increase of 1% in R&D spillover could result in a 0.075% unit of productivity increase. The contribution of intra-industry R&D spillover effects to productivity was greater than the contribution of an individual company's R&D expenditure, indicating that effective improvements in the R&D level of the optoelectronic industry can lead to better results than the contributions of individual companies.

Regarding the empirical results of the photoelectric information sub-sample, as shown in Table 4 Panel A, the elasticity of R&D expenditure and R&D spillover was 0.109 and 0.123, respectively, indicating every 1% increase in R&D expenditure and R&D spillover could result in a 0.109% unit of productivity output and a 0.123% unit productivity increase (see Table 4 Panel A). In the industrial clusters of optical information products, such as CD-ROMs, scanners, digital cameras and other relevant industries, Taiwanese manufacturers have been ranked in the world's top three in terms of production, and the industry has entered the maturity stage. This suggests that manufacturers of this cluster have achieved economies of scale.

Table-1. Statistics of Variables (NT\$ Thousands)

Y	Full-sample	Sub-sample			
	Industry	Information	Display	Component	Communication
Mean	3,524,700	3,077,925	6,150,728	1,630,131	5,505,359
(S.E.)	1.09e+07	6,669,482	1.60e+07	5,907,437	1.52e+07
CAP	Industry	Information	Display	Component	Communication
Mean	6,239,622	3,250,064	1.85e+07	1,372,313	975,514
(S.E.)	2.77e+07	8,243,458	5.25e+07	1,911,937	1,043,341
LAB (people)	Industry	Information	Display	Component	Communication
Mean	973	671	2,008	537	790
(S.E.)	1947	922	3,429	654	896
RDI	Industry	Information	Display	Component	Communication
Mean	80,490	67,828	151,045	30,473	97,472
(S.E.)	196,653	130,222	324,281	78,290	164,841
RDS (%)	Industry	Information	Display	Component	Communication
Mean	0.0002804	0.0007893	0.0011186	0.0011287	0.0015175
(S.E.)	0.0006851	0.0015153	0.0024015	0.0028997	0.0025662

Source: Taiwan Economics Journal, (TEJ).

Most of their manufacturing bases have been set up in mainland China. When products enter the maturity stage, how to increase R&D investment in new products, how to apply new technology, and how to create new consumption needs are important topics for the photoelectric information industry.

In Panel B are the results of the photoelectric display sub-sample. Only R&D expenditure, R&D spillover and labor had a significant impact on productivity, indicating that investment in fixed assets would not significantly affect productivity. The race for new generation panel equipment may not improve productivity but could easily land manufacturers in financial difficulties and lead to corporate crises. The coefficients of R&D expenditure and R&D spillover were 0.061 and 0.060, indicating that every 1% increase in R&D expenditure and R&D spillover could result in a 0.061% unit of productivity output and 0.060% unit of productivity output. The R&D effects of various companies are equivalent to the inter-industry R&D spillover effects.

Table-2. Results of Panel Data Model Test.

Sample	F test	LM test	Hausman test	Model
Information	132.40***	11498.46***	8.94*	Fixed effect
Display	11.13***	394.96***	36.35***	Fixed effect
Component	101.76***	5900.26***	17.45***	Fixed effect
Communication	62.30***	2631.16***	36.26***	Fixed effect
Industry	44.87***	15915.24***	50.71***	Fixed effect

Notes: Terms ***, **, and * represent the 1%, 5%, and 10% significance levels, respectively.

Table-3. Empirical Results of Full-sample Model (Optoelectronic Industry).

Variable	Coefficient	Standard Error
Constant	3.878***	0.109
lnCAP	-0.059***	0.023
lnLAB	0.921***	0.034
lnRDI	0.060***	0.010
lnRDS	0.075***	0.010

Notes: Terms ***, **, and * represent the 1%, 5%, and 10% significance levels, respectively.

If the government could effectively strengthen the technological development of the overall industry, it could better help improve the technological capabilities of the optoelectronic industry.

With respect to the empirical results of the photoelectric component sub-sample, as shown in Panel C, R&D expenditure and R&D spillover had a significant impact on productivity. The elasticity of R&D expenditure was 0.027, indicating that every 1% increase in R&D expenditure could result in a 0.027% unit of productivity increase. The coefficient of R&D spillover was 0.048, indicating that every 1% increase in R&D spillover could result in a 0.048% unit of productivity output increase. The impact of R&D spillover on the photo electronic components industry's productivity was far greater than the R&D expenditures of individual manufacturers. It suggests that the mutual effects of R&D in the cluster are more significant than other clusters.

Table-4. Empirical Results of Sub-sample Model.

Panel A: Optoelectronic Information

Variable	Coefficient	Standard Error
Constant	4.867***	0.123
lnCAP	-0.083***	0.022
lnLAB	0.614***	0.041
lnRDI	0.109***	0.013
lnRDS	0.123***	0.014

Panel B: Optoelectronic Display

Variable	Coefficient	Standard Error
Constant	2.316***	0.302
lnCAP	-0.092	0.072
lnLAB	1.469***	0.097
lnRDI	0.061**	0.030
lnRDS	0.060***	0.023

Panel C: Optoelectronic Component

Variable	Coefficient	Standard Error
Constant	3.974***	0.194
lnCAP	0.054	0.040
lnLAB	0.567***	0.044
lnRDI	0.027**	0.011
lnRDS	0.048***	0.015

Panel D: Optoelectronic Communication

Variable	Coefficient	Standard Error
<i>Constant</i>	6.290***	0.205
<i>lnCAP</i>	-0.181***	0.041
<i>lnLAB</i>	0.400***	0.067
<i>lnRDI</i>	0.195***	0.019
<i>lnRDS</i>	0.380***	0.028

Notes: Terms ***, **, and * represent the 1%, 5%, and 10% significance levels, respectively.

If the government can effectively improve the technology of the overall industry, it can effectively help improve the industry's productivity.

The empirical results of the photoelectric communication sub-sample, as shown in Panel D, the elasticity of R&D expenditure was 0.195, indicating that every 1% increase in R&D expenditure could result in a 0.195% unit of productivity output increase. The coefficient of R&D spillover was 0.380, indicating that every 1% increase in R&D spillover could result in a 0.380% unit of productivity output increase. The industrial R&D spillover effects of the optical communication cluster had nearly double the effect of the R&D expenditure of individual companies, suggesting that intra-industry R&D investment can promote the production effectiveness of the overall industry. The effective improvement in R&D spillover can better help the improvement of the productivity of the photoelectric communication industry.

5. CONCLUSIONS AND SUGGESTIONS

5.1. Conclusions

The empirical results suggested that for both the total sample and the sub-samples of the optoelectronic industry, R&D expenditure and R&D spillover effects have positive contributions to productivity. In addition, other than the optical display sub-sample, the empirical results of the sub-samples suggested that the productivity improvement effect caused by the R&D spillover effects is better than that caused by the R&D expenditure variable. This result was consistent with the findings by [Terleckskyj \(1974;1982\)](#) who argued that the return rate of R&D spillover effects was about 45% and the return of self-engagement in R&D was only 28%, as well as [Nadiri and Wolff \(1987\)](#) argued that inter-industry R&D spillover rewards are far greater than those of their own R&D investment, and [Goto and Suzuki \(1989\)](#) argued that the investment return rate of individual industries receiving external R&D capital is more than three times the rewards of the private R&D investment of the industry.

Regarding the photoelectric sub-sample, the impact of R&D expenditure on productivity was equivalent to the R&D spillover, suggesting that the strengthening of R&D spillover can have the same R&D effect. With the photo-electronic component sub-sample, the impact of R&D spillover on the productivity of the photo-electronic component industry is more significant than that of the R&D expenditure of the companies, suggesting that the mutual effect of the R&D spillover effects within the industrial cluster is very strong. Regarding the optical communication sub-sample, the industrial R&D spillover effects had nearly double the effect on the R&D expenditures of individual companies, indicating that the optical communication industry's R&D spillover effects can significantly boost a company's productivity.

In summary, although Taiwan's optoelectronic industry has considerable assembly application capabilities and a complete background of related industries, the mastering of core technology and the development of key components still need to be strengthened. Based on strong photo-electronics, information and manufacturing capacities, an in-depth study should be carried out by integrating these different fields and focusing on intellectual properties to create applications with high added value, high precision and a high price through R&D innovations. This way, Taiwan manufacturers can continue to the market and promote overall social and economic development.

5.2. Application and Suggestions

The optoelectronic industry in Taiwan has developed over twenty years, and now occupies a pivotal place in the global market. However, past experience cannot guarantee the creation of the next golden age. The Taiwanese optoelectronic industry mainly produces OEM/ODM products and fails to create distinctive brands for sales, and thus, it has no price-making capabilities. Once faced with price competition or excessive supply or demand caused by financial crises, profitability will decline. The following are suggestions for different institutions on how to improve the R&D capabilities of the optoelectronic industry and create unique technical values. These suggestions are aimed at empowering the Taiwanese optoelectronic industry with core competitiveness and exclusive power to overcome the competition and challenges in the global market.

Governmental agencies should set up specific industrial parks to encourage private investment in optoelectronic industry R&D, and should grant special preferential policies regarding land, taxation and capital sources to develop the clustering effect of relevant industries. The intra-industry R&D spillover effects can further promote the intra-industrial technicality and productivity. Governmental agencies should also use public power to combine excessive numbers of companies in similar industries. This can avoid excessive numbers of competitors and maximize corporate value, and the application of technical sources can be achieved through resource integration.

The optoelectronic industry relies on innovative thinking, improvements in manufacturing processes, and the introduction of new technology and the vertical integration of upstream and downstream suppliers to reduce production costs and improve the output rate. It also relies on the R&D of new products to make breakthroughs in response to financial issues or future challenges. Although the optical information industry is facing the maturity stage, it may invest in the R&D of new products or the integration of existing products (such as applications for blue-ray discs, digital photo frames and touch panels). The value of the optical display industry lies in new technology development and the technical vertical integration of upper and downstream suppliers. In the past, large investments in fixed assets were used to build new generation panel production technology and improve the panel cutting rates. However, the capital cost and opportunity cost will result in a heavy financial burden when faced with financial distress. The integration of innovative manufacturing processes and new technological developments to improve production outputs and reduce material costs, combined with intra-industrial R&D spillover, can help the sustainable development of this industrial cluster.

The value of the photo-electronic components industry lies in how to use new ideas to create new industrial applications and new market demands, in addition to existing fields, to achieve the objective of market growth. The limitless space of ideas and applications can create new applications for existing products. For example, the replacement of traditional light sources by LED devices can strike a balance between the revenue and gross profits of the industry.

LEDs have a wide range of applications. The backlight sources of mobile devices such as mobile phones, signal displays, and the indicators used in electronic equipment and automobiles can be regarded as four application markets for LED products. Coupled with green ideas and energy saving advantages, LEDs will have a very wide range of applications in the future and will stimulate demands and applications for new products. For example, low-priced computers, such as the Eee PC, will use LED backlight modules to take the place of traditional fluorescent lights. The industrial cluster of optical communications should strengthen product quality reliability, improve production output rates and reduce production costs when building optical fiber broadband networks across the world, in order to expand the production scale of the optical fiber broadband supply chain.

The role of academic institutions should be to integrate the academic side with the practical side by applying the original academic theories in practical applications for maximized value. During seminars, industry representatives and academics can further exchange knowledge and work together to create new technology. Through scientific and technological projects, the technical costs of the industry can be transferred to the R&D of academics with government subsidies. Meanwhile, the research findings can be fed back to the industry to

effectively promote the R&D achievements and applications in products. Academic institutions can create innovative incubation centers to invite and cultivate small and medium enterprises and can provide them with technical support and facilities to achieve the purpose of creating new technologies and new products.

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