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The Spillover Effects of Investment, Economic Growth and Electricity Consumption: An Application Mathematical Dynamic Industry-Related Models Approach#

Cheng-Yih Hong[1], Yu-Shuang Yen[2]*, Tsai-Rong Lee[3]

[1]Faculty of Finance, Chaoyang University of Technology, Taiwan, [2]Department of Business Administration, Chaoyang University of Technology, Taiwan, [3]Taipei Municipal Zhongshan, Girls High School, Taichung, Taiwan. *Email: hcyih@cyut.edu.tw

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ABSTRACT

The economic growth pattern of investment has been proved in Asian countries, but it often falls into development bottleneck after the economy develops to a certain extent, especially in countries with lack of resources. One of the important reasons is the supply of energy and electricity. Establishing a sustainable development path requires thinking about economic development and environmental protection at the same time. This will face how to establish a balanced industrial structure and a stable electricity supply system, and investment in production equipment and research and development (R&D) will be an indispensable factor. R&D investment and equipment investment contribute to economic growth. This study employs a dynamic industry-related model to estimate the economic spillover effect from both R&D investment and equipment investment. The present study attempts to measure (1) the difference in the investment multiplier of R&D investment and equipment investment, (2) the difference in the employment creation effect of investment R&D and equipment investment. Analysis of future industrial development strategies needs to consider energy and electricity consumption. This study will estimate (3) the impact of equipment investment and R&D investment on power consumption, and compare the differences between the two on the industry. This study uses mathematical dynamic industry-related models to estimate (1) ~ (3) and found that different investment methods will make the inter-industry economy have different spillover effects, and also show different demand in power consumption.

Keywords: Research and Development Investment, Equipment Investment, Dynamic Industry-Related Model, Electricity Consumption
JEL Classifications: C60, O30, Q43, Q56

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1. INTRODUCTION

Under the influence of liberalization in the 1990s, Taiwan was pressured by the international community to relax control on trade and the financial market. To address the issues of slow economic growth and environmental protection needs, the government launched a 6-year National Development Plan (1991-1996) to achieve full-scale balanced development. Nevertheless, Taiwanese industry structures have remained unadjusted because of insufficient domestic investment and massive capital outflows. The global financial crisis in 2008 has resulted in a severe economic downturn in Taiwan, highlighting the enduring failure in industrial restructuring and the necessity of a policy review (Hong and Li, 2015). After the financial crisis, governments and companies tried to solve economic shocks with research and development (R&D) and equipment investment strategies to increase employment and increase competitiveness.

Numerous studies have shown that energy price fluctuations can cause tremendous economic loss when economic growth hinges excessively on energy consumption (Bruno and Sachs, 1985; Hamilton, 1983; Davis and Haltiwanger, 2001; Lee, et al., 2002;Hong and Hsu., 2018). Therefore, the stability of energy prices does not only affect production costs but also constitutes a vital factor influencing economic development (Huang et al., 2015a; 2015b). How to achieve economic development given these conditions in Taiwan warrants discussion? Over the past two decades, high technology has become the driver fueling economic growth in Taiwan. Nevertheless, sustained R&D is imperative for maintaining competitiveness in high technology industries. Effective R&D investment can boost productivity and create added values (TV) (Hong et al., 2017).

Improved productivity can increase profits by reducing energy consumption while achieving the objective of economic growth (Heintz et al., 2009;Ramey, 2011). Huang et al. (2015a; 2015b) found that following its entry into the World Trade Organization, Taiwan has exhibited increasingly high imported-energy intensity and considerably heightened sensitivity to energy prices, implying the Taiwanese economy has become more restricted by its reliance on energy. Achieving sustainable economic development in a country necessitates advances in R&D technologies and equipment investment, which enable a country to adapt to changes in the international economic environment and realize industrial restructuring (Hong et al., 2017).

On the other hand, Taiwan's economic development requires a stable supply of electricity, and advanced equipment renewal is a way to improve energy efficiency. Economic development and industrial structure affect electricity consumption, and the electricity consumption coefficient of the industry also affects the level of electricity consumption. The stability of energy and electricity supply has become a key factor in Taiwan's economic development, through R&D and production equipment renewal as one of the solutions. This research focuses on the economic effects of R&D and equipment investment, and estimates the electricity consumption of the industry, and compares the spillover effects of R&D and equipment investment between different industries. In order to achieve the above issues, this paper will use economic dynamic industry-related models to analyze economic effects and electricity consumption.

2. LITERATURE REVIEW

Investing in economic development is the experience of many countries, but it is accompanied by environmental pollution. The development experience in the East Asian region is to achieve economic growth through investment. There are many ways to invest, such as R&D, equipment updates, or infrastructure. Investment to increase economic efficiency through R&D or equipment renewal to drive economic growth. But as economic growth increases energy consumption (Lee, 2006; Ewing et al., 2007; Ozturk, 2010; Acaravci and Ozturk, 2010; Ozturk and Acaravci, 2011), the increase in electricity demand has led to a significant increase in gas emissions. Both growth hypothesis and conservation hypothesis point to the important relationship between power consumption and good economic development, but the two hypotheses also have different opinions. Among them, Ozturk and Acaravci (2011) found that among the countries surveyed, some countries did not show a cointegration relationship between electricity consumption and economic growth.

In addition, there are some literatures that analyze the relationship between economic growth and electricity consumption from the perspective of urbanization (Lenzen et al., 2006; Parshall et al., 2010; Liddle, 2013; Liddle and Lung (2014); Salim and Shafiei, 2014; Liddle and Messinis, 2015; Kasman and Duman, 2015). Both Parshall et al. (2010) and Salim and Shafiei (2014) have found a positive correlation between electricity consumption and urbanization, and Liddle's (2013) study proves that urbanization is related to economic growth.

Grossman and Krueger (1991) pointed out that after the economic development reaches a level, the environmental Kuznets curve phenomenon will occur, but a sustainable economic development is considered together with the environmental impact of energy consumption and greenhouse gas emissions. However, with the changes in the international environment, from liberalization, internationalization to globalization, some studies have analyzed the pollution haven hypothesis from international trade (Hong et al., 2017;Behera and Dash, 2017; Solarin et al., 2017) Sun et al., 2017; Zhu et al., 2016; Zhang and Zhou, 2016; Zakarya et al., 2015; Dean et al., 2004; Dasgupta et al., 1999; 2001).

3. EMPIRICAL MODEL

3.1. Industry-Related Spillover Model

The supply-demand equilibrium equation of the competitive import type of the industry-related spillover model could be constructed as.

$$\sum_{j=1}^{n} x_{ij} + F_i^d + E_i = X_i + M_i, i = 1, 2, n \tag{1}$$

$$\sum_{j=1}^{n} a_{ij} X_j + F_i^d + E_i = X_i + M_i, i = 1, 2, n \tag{2}$$

where $a_{ij} = x_{ij}/x_j$; a_{ij} is the input coefficient which denotes the input from industry i per output for industry j ($i = 1,\ldots, n; j = 1,2,\ldots n$); x_j represents the total output of industry j and x_{ij} stands for per output for industry j resulting from the input of industry i.

$$M_i = m_i \left(\sum_{j=1}^{n} a_{ij} X_j + F_i^d\right), i = 1, 2, n \tag{3}$$

Combining equations (2) and (3), we obtained as follows

$$X_i - (1 - m_i)\sum_{j=1}^{n} a_{ij} X_j = (1 - m_i) F_i^d + E_i, i = 1, 2, n \tag{4}$$

In terms of matrix, equation (4), which is the competitive import type of the industry-related spillover model, could be rewritten as.

$$X = [I - (I - \bar{M}) A]^{-1}[(I - \bar{M}) F^d + E] \tag{5}$$

$[I - (I - \bar{M}) A]^{-1}$ is the Leontief inverse matrix, which is so called Leontief multiplier. To compare the differences in the investments made by the private and public sectors, we compiled the following equilibrium equations for the dynamic industry-related model:

$$X(t) = AX(t)+C^P+C^G+K[X(t-1)-X(t)] \quad (6)$$

Based on the value-added rate, the earning of enterprises and laborers ($y(t)$) can be estimated using.

$$y(t) = V^t X(t) \quad (7)$$

V^t is the vector of the value-added rate.

$$C^P = H_c\, c\, y(t) = H_c\, c\, V^t X(t) \quad (8)$$

c is the consumption rate, and H_c is the vector of consumption patterns.

$$X(t) = AX(t)+(C^P+C^G)X(t)+k^p+k^g\,[X(t+1)-X(t)] \quad (9)$$

where C^P is private sector consumption and C^G is government sector consumption; k^p is private sector investment and k^G is government sector investment, as shown in the following equations:

Specifically, the scale of government consumption (C^G) is determined by budgetary planning. Therefore, $C = H_c\, c\, V^t X(t)+C^G$.

Assuming $D = I-A-C$, the dynamic model can be written as

$$X(t+1) = (K^{-1}D+I)X(t) \quad (10)$$

In this study, we adopted an industry-related model featuring open competition. Therefore, the dynamic industry-related model is,

$$X(t+1) = \left(K^{-1}D+I\right)\left[I - A\left(I-\bar{M}\right)\right]^{-1}\left[E+\left(I-\bar{M}\right)F^d\right] \quad (11)$$

When estimating the intrinsic value and intrinsic vector of $(K^{-1}D+I)$ in (10), let η be the intrinsic value of $D^{-1}K$ and the intrinsic vector be τ:

$$D^{-1}K\tau = \eta\tau$$

$$\left(K^{-1}D+I\right)\tau = \left(\frac{1}{\eta}+1\right)\tau$$

$(\frac{1}{\eta}+1)$ is the intrinsic value of $K^{-1}D+1$, and τ is the corresponding intrinsic vector.

$$X(t+1) = \left(K^{-1}D+I\right)\left[I - A\left(I-\bar{M}\right)\right]^{-1}\left[E+\left(I-\bar{M}\right)F^d\right] \quad (12)$$

Following equation (12), in the present study we would estimate the direct, the first, the second direct spillover effects. The measures could be constructed

Measurement of the direct and indirect effects

The direct effects

The direct effect is the product of change in domestic final demand δF_i^d and rate of self-supplying $(I-\bar{M})$, that is.

$$(I-\bar{M})\delta F_i^d \quad (13)$$

Total economic spillover effects

Let Leontief inverse matrix be $(K^{-1}D+I)[I-A(I-\bar{M})]^{-1}$, Γ^* the formula that we could estimate the total economic spillover effects of the consumption expenditures from Chinese tourists on Taiwan's economy could be restated as

$$\underbrace{TESE}_{\text{Total Economic Spillover Effects}} = \underbrace{(I-\bar{M})\delta F_1^d}_{\text{Direct Spillover Effects}} + \underbrace{\Gamma^*(I-\bar{M})\delta F_1^d}_{\text{First Indirect Spillover Effects}} + \underbrace{\Gamma^*(I-\bar{M})\delta F_2^d}_{\text{Second Indirect Spillover Effects}} \quad (14)$$

3.2. Measurement of the Persons Employed

The total gross induced TV is formulated as equation (15), consisting of the direct gross TV, the first and the second indirect gross TV.

$$\underbrace{TV}_{\text{Total Gross Induced Added Value}} = \underbrace{w_j^G(I-\bar{M})\delta F_1^d}_{\text{Direct Gross Induced Added Value}} + \underbrace{w_j^G\Gamma^*(I-\bar{M})\delta F_1^d}_{\text{First Indirect Gross Induced Added Value}} + \underbrace{w_j^G\Gamma^*(I-\bar{M})\delta F_2^d}_{\text{Second Indirect Gross Induced Added Value}} \quad (15)$$

The formula for total induced income of employment (TE) that we could estimate the direct and indirect induced income of employment.

$$\underbrace{TE}_{\text{Total Induced Income of Employment}} = \underbrace{w_j^L(I-\bar{M})\delta F_1^d}_{\text{Direct Income of Employment}} + \underbrace{w_j^L\Gamma^*(I-\bar{M})\delta F_1^d}_{\text{First Indirect Induced Income of Employment}} + \underbrace{w_j^L\Gamma^*(I-\bar{M})\delta F_2^d}_{\text{Second Indirect Induced Income of Employment}} \quad (16)$$

We developed a dynamic model that features investment as an endogenous factor to estimate electricity consumption.

3.3. Electricity Consumption Estimate

$$Electricity\ Consumption = \underbrace{E^{Electricity}(I-M)\delta F_1^d}_{\text{Direct Spillover}} + \underbrace{E^{Electricity}\Gamma^*(I-M)\delta F_1^d}_{\text{First Indirect Spillover}} + \underbrace{E^{Electricity}\Gamma^*(I-M)\delta F_2^d}_{\text{Second Indirect Spillover}} \quad (17)$$

$$E^{Electricity} = \begin{pmatrix} e_1^{Electricity} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & e_n^{Electricity} \end{pmatrix}$$

$$e_j^{Electricity} = \frac{Electricity_j}{x_j},\ j = 1,2\ldots n$$

Where the electricity consumption coefficient $e_j^{Electricity} = Electricity_j / x_j$, and $E^{Electricity}$ is the diagonal matrix of the elements of the electricity consumption coefficients for various industries.

4. EMPIRICAL RESULTS

4.1. Economic Spillover Effects of Investment

Based on the nature of the industries, we divided the 166 sectors listed in The Report on 2015 input-output tables into seven major industries. Table 1 shows the economic effects of R&D investment on various industries. The results indicate the effects were most prominent in the machinery and service industries, accounting for 36% and 33.69% of the overall effects, respectively.

This is primarily because R&D involves the purchase of raw materials used to produce machinery and electronics-related products, indirectly increasing the crude value-added and income from employment in relevant industries. This triggers subsequent demands for the machinery and electronics industries and the service industry.

Regarding the economic effects of equipment investment on various industries, equipment investment had the most significant economic spillover effects on machinery-related industries and the infrastructure industries, as shown in Table2.

Specifically, the economic effects on machinery-related industries accounted for 50.92% of the overall economic spillover effect. The effect on the infrastructure industries accounted for 26.77% of the overall effect. The results differed slightly from the effects of government sector investment. This is primarily because private investments in electronics-related industries are equipment investment. Although improving production technologies can enhance productivity, 30% of the equipment is imported. Consequently, the direct economic spillover is minor.

Both R&D investment and equipment investment exhibited decreased first economic spillover effects on agriculture-related industries and the light industries. Nevertheless, the ultimate economic spillover effect of R&D investment increased whereas equipment investment had negative economic effects on agriculture-related industries.

4.2. Employment Effects of Investment

Estimations regarding the number of jobs created in various industries by R&D investment and equipment investment are

Table 1: Economic effect of R&D investment

Sector	Raw material induced value	First spillover effects	Second spillover effects	Total (%)
Agriculture-related	84.32	−91.91	1,750.71	1,743.12 (2.10)
Light industry	821.07	−192.17	724.98	1,353.87 (1.63)
Chemical-related	4,562.62	5,429.43	1,481.23	11,473.27 (13.85)
Iron, Non-Iron	1,337.05	−810.85	172.42	698.62 (0.84)
Machinery-related	17,106.58	7,723.94	4,985.54	29,816.07 (36.00)
infrastructure	958.60	9,778.06	−894.86	9,841.81 (11.88)
Service-related	17,490.07	6,580.07	3,835.51	27,905.64 (33.69)
Total	42,360.31	28,416.57	12,055.53	82,832.41 (100.00)

Unit: Million New Taiwanese Dollars, R&D: Research and development

Table 2: Economic spillover effects of equipment investment

Sector	Raw material induced value	First spillover effects	Second spillover effects	Total (%)
Agriculture-related	11.42	−2,101.21	1,235.47	−854.32 (−0.85)
Light industry	480.95	−77.55	511.61	915.01 (0.91)
Chemical-related	2,906.40	3,996.54	1,045.29	7,948.23 (7.94)
Iron, Non-iron	2,269.12	−1,220.53	121.69	1,170.28 (1.17)
Machinery-related	43,906.21	3,561.69	3,518.30	50,986.20 (50.92)
Infrastructure	828.23	26,606.72	−631.51	26,803.44 (26.77)
Service-related	6,903.73	3,550.17	2,706.73	13,160.63 (13.14)
Total	57,306.07	34,315.83	8,507.58	100,129.48 (100)

Unit: Million New Taiwanese Dollars

Test 3: Employment creation on industries

Sector	(1) R&D investment		(2) Equipment investment		(3)=(1)-(2)
	Employment creation (persons)	Coefficient of employment (persons per million dollars)	Employment creation (person)	Coefficient of employment (Person per million)	(person)
Agriculture- related	804	0.46	−1,338	1.5	2,142
Light industry	669	0.49	135	0.15	534
Chemical- related	3,082	0.27	1,258	0.16	1,824
Iron, Non-Iron	402	0.58	603	0.52	−201
Machinery- related	6,483	0.22	7,483	0.15	−1,001
Infrastructure	3,378	0.34	5,731	0.21	−2,353
Service-related	14,582	0.52	7,000	0.53	7,582
Total	29,400	0.35	20,872	0.21	8,528

R&D: Research and development

Table 4: Electricity consumptions of R&D investment

Sector	Raw material induced value	First spillover effects	Second spillover effects	Total (%)
Agriculture-related	0.46	−0.50	9.57	9.53 (1.77)
Light Industry	6.23	−1.46	5.50	10.28 (1.91)
Chemical-related	11.01	13.10	3.57	27.69 (5.15)
Iron, Non-Iron	23.67	−14.36	3.05	12.37 (2.30)
Machinery-related	123.69	55.85	36.05	215.59 (40.12)
Infrastructure	17.16	175.05	−16.02	176.19 (32.79)
Service-related	53.73	20.21	11.78	85.72 (15.95)
Total	235.96	247.90	53.51	537.37 (100.00)

Unit: GWh, R&D: Research and development

Table 5: Electricity consumptions of equipment investment

Sector	Raw material induced value	First spillover effects	Second spillover effects	Total (%)
Agriculture-related	0.06	−11.48	6.75	−4.67 (−0.50)
Light industry	3.65	−0.59	3.88	6.95 (0.75)
Chemical-related	7.01	9.64	2.52	19.18 (2.06)
Iron, Non-Iron	40.17	−21.61	2.15	20.72 (2.23)
Machinery-related	317.47	25.75	25.44	368.67 (39.59)
Infrastructure	14.83	476.33	−11.31	479.85 (51.53)
Service-related	21.21	10.91	8.31	40.43 (4.34)
Total	404.41	488.95	37.76	931.12 (100.00)

Unit: GWh

shown in Table 3. Although the economic spillover effect of R&D investment was most prominent in machinery-related industries, the largest number of jobs created was in service-related industries (14,582 jobs) because the employment multiplier was greater. By contrast, the largest number of jobs created by equipment investment was in machinery-related industries (7,483 jobs). Nevertheless, the economic spillover effect on agriculture-related industries was negative; consequently, the number of jobs created decreased by 1,338.

The gap between the number of jobs created by R&D investment and equipment investment was most significant in service-related industries, with a difference of 7,582 jobs. However, compared with R&D investment, private investment created more jobs in infrastructure industries and machinery-related industries, with a difference of 2,353 and 1,001 jobs, respectively. In addition to reflecting the difference in the economic spillover effects, the difference in the number of jobs created also showed R&D investment and equipment investment differed in employment multiplier. This result indicates that the employment effect of R&D investment was superior to that of equipment investment in high technology equipment.

4.3. Electricity Consumptions of Economic Spillover Effects

Table 4 shows the economic impact of R&D's investment in electricity consumption. The data shows that machinery-related industries account for 40.12% (215.59 GWh), followed by infrastructure (32.79%) and service-related (15.95%). Agriculture-related and light Industry have less economic impact due to R&D, so electricity consumption only accounts for 1.77% (9.53 GWh) and 1.91% (10.28 GWh), which means that R&D's investment effect is relatively high in the high-tech machinery-related industry.

Table 5 shows the power consumption required for the economic effects of equipment investment. From the empirical results, the infrastructure industry consumes the most electricity, up to 479.85 GWh, accounting for 51.53% of the total electricity consumption. Followed by the machine-related 368.67 GWh (39.59%). It is worth noting that the agriculture-related electricity consumption is negative (−4.67 GWh), mainly due to the shift in investment and the reduction in production caused by the increase in the infrastructure industry. In addition, the impact of equipment renewal investment on service-related industry is smaller than R&D's investment, and the service-related department's electricity consumption is only 40.43 GWh.

5. CONCLUDING REMARKS

We analyzed the economic spillover effects of R&D investment and equipment investment as well as the number of jobs created. The effects of economic growth involve gross value-added for enterprises, income from employment, and job opportunities. Gross value-added, as a basis of capital accumulation, can increase the level of subsequent investment. In addition, the technologies accumulated can contribute to a virtuous cycle of investment. Furthermore, increased income from employment and job opportunities can improve spending power, ultimately increasing market demands. On the other hand, when thinking about Taiwan's economic development in the future, we need to consider the issue of energy and electricity consumption. Sustainable economic development requires not only investment in production equipment, but also R&D. This study divides investment into equipment investment and R&D investment. It hopes to further clarify the economic and environmental differences between the two, which will help the strategic path of future industrial development. The following paragraphs present the empirical results obtained in this study:

1. The investment multiplier of R&D was 1.40, which was greater than that of equipment investment (1.07). The main

difference lies in the size of the direct economic spillover effects. Both types of investments had the greatest economic spillover effects on machinery-related industries. The value of investment multiplier reflects the economic spillover effects of investment. In addition to purchasing equipment, R&D investment is also spent on human resources cultivation. These factor input can be satisfied using domestic resources, and the economic spillover effects of the spending can be easily formed domestically. By contrast, equipment investment in equipment relies considerably on importation. In particular, a large proportion of the high technology equipment necessary in capital-intensive industries is imported. Consequently, the economic spillover effect of equipment investment was not comparable to that of R&D investment.

2. R&D investment created the most job opportunities in service-related industries, whereas equipment investment created the most job opportunities in machinery-related industries. Overall, R&D investment created more jobs than private investment. The number of jobs created is determined by the size of investment and the employment coefficient of an industry. In this study, we used NT$100 billion as the initial investment for all industries; therefore, job creation is determined by employment coefficients. Generally speaking, employment coefficient is a key indicator employed to differentiate between capital- and labor-intensive industries. The value of employment coefficient determines the number of jobs created by an investment. The results of this study show R&D investment evidently had a greater effect on job creation. This is because increased value-added for enterprises and increased income from employment affected the economic spillover effects on service-related industries, which had relatively high employment coefficients.
3. R&D invests in the largest demand for electricity in machinery-related industries, while equipment investment is the largest in terms of electricity demand in infrastructure-related industries. The main reason is that investment projects are related to the self-sufficiency rate of investment products. The electricity consumption of equipment investment is 931.12 GWh, and the electricity consumption of R&D investment is relatively small, only 537.37 GWh.
4. From the results of (1) to (3), it is found that the investment methods are different, and the economic spillover effects on all industries are also different. Therefore, it also appears in the demand for electricity in various industries.

Nearly 99% of Taiwan's energy consumption needs to be imported. The road to sustainable development must consider how to balance economic growth and environmental protection. This study analyzes investment equipment updates and R&D to promote economic growth. On the other hand, discussions will increase energy and power efficiency to reduce electricity use.

Taiwan faces the bottleneck of industrial restructuring, which makes the economy unable to develop smoothly. To solve this problem, renewable energy is used to replace the energy policy of thermal power generation. The transformation of energy policy will drive R&D investment in renewable energy equipment and power systems, which will change Taiwan's industrial structure and power sources, and the future economic development model will be different from the past. Take Taichung area as an example. Taichung City subsidizes more than 2 metric tons of oil-fired boilers to change gas-fired boilers to reduce CO_2 and PM2.5 emissions (the subsidy scale is equivalent to about 80% of the city's boilers). Such a policy can not only create economic growth, but also improve the environment. In addition, Taichung's renewable energy investment is also a concrete step towards the sustainable development of the city.

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