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Investment, Energy Consumption and CO_2 Emissions: An Analysis on the Strategy of Industry Development[1]

Cheng-Yih Hong[1]*, Chung-Huang Huang[2], Jian-Fa Li[3]

[1]Faculty of Finance, Chaoyang University of Technology, Taiwan, [2]Taiwan Research Institute, Taiwan, [3]Faculty of Finance, Chaoyang University of Technology, Taiwan. *Email: hcyih@cyut.edu.tw

ABSTRACT

This study employs a dynamic environmental industry-related model to estimate the economic spillover effect and the CO_2 emissions from both research and development (R and D) of government and private equipment investment. We classify the industries into four subgroups which are the high economic effect with high emission coefficient, low economic effect with high emission coefficient, low economic effect with low emission coefficient and high economic effect with low emission coefficient. The present study attempts to measure the CO_2 emission of both governmental R and D and private equipment investment, and further to propose the direction of Taiwan's industrial development.

Keywords: Investment, CO_2 Emission Coefficient, Dynamic Environmental Industry-related Model
JEL Classifications: C6, Q50, Q58

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1. INTRODUCTION

Economic growth and environmental protection seem to have presented themselves as two incompatible paths. Indeed, the economic growth in Taiwan has incurred environmental damages that are ongoing. How to minimize environmental pollution while sustaining economic growth has become a critical issue in the course of forming a quality society in the country.

Achieving industrial restructuring by engaging in high technology research and development (R and D) can be used as a means for resolving the economic problems in Taiwan and for achieving environmental preservation. In addition, effective industrial restructuring can drive economic development and create more job opportunities. Taiwanese economic growth relies heavily on exportation and is highly subject to the influence of the global economy, thereby resulting in a vulnerable economic constitution. Furthermore, the developments of the high technology industries, which can yield high added values, are incomplete due to the serious lack in capital, equipment, and technology. These factors have hindered Taiwanese industry upgrading, preventing industrial restructuring.

The static-efficiency in market allocation and the dynamic gain of productivity are two vital factors powering structural economic changes, ultimately enabling economic development. These ideas are consistent with the concept of creative destruction developed by Joseph A. Schumpeter, a celebrated economist in the twentieth century. Specifically, the transfer and acquisition of knowledge and technology enhances production potential, which is realized through investment. Well-adjusted industry structures can improve the environment; hence, economic development can be achieved while satisfying Taiwanese people's expectation of environmental protection.

The government, which plays a vital role in R and D, is responsible for leading the industrial development and restructuring in Taiwan. Nevertheless, amid the rapidly changing global economic environment, many countries are catching up with Taiwan economically. Consequently, previous R and D pace and strategies can no longer prepare Taiwan for the economic challenges posed by other countries. Considering the current industrial development and economic structure in Taiwan, developing high technology industries matches future development trends. High technology industries, which can act as a driver fueling economic growth, can reduce CO_2 emissions and achieve the objective of environmental protection. Hence, we used high technology industries as the subject of this study to calculate the economic effects of R and D investment before using the results to estimate CO_2 emissions.

We divided the investing sectors into the government and private enterprises. Specifically, the government invests in R and D while private enterprises invest in equipment. Differing ways of investment yield differing economic benefits and environmental impact, and the same investment can also result in varying effects on differing industries. In previous studies, economic effects and CO_2 emissions have been estimated primarily using the static model, which is suitable for conducting short-term analysis. Nevertheless, investment results cannot be explained effectively based on short-term analysis. Therefore, we developed a dynamic model that features investment as an endogenous factor to estimate economic effects and CO_2 emissions.

2. LITERATURE REVIEW

The literature on investment is focused heavily on the influence of government public spending on economy (Fishback and Kachanovskaya, 2010; Ramey, 2011; Parker, 2011; Hong and Li, 2015). Ramey (2011) estimated that the temporary investment multiplier devised by the US government was between 0.5 and 2.0. Fishback and Kachanovskaya (2010) found the highest public investment multiplier during the U.S. New Deal period was 1.7. Parker (2011) confirmed that the effect of investment multiplier is optimal when the economy of a country is in recession. Furthermore, Romp and de Haan (2005) concluded the elasticity of the output of high-income countries over public capital was between 0.1 and 0.2. Heintz et al. (2009) indicated that every US$1 billion can generate 18,000 jobs in various industry sectors. Hong and Li (2015) examined a plan the Taiwanese government implemented during the 2008 financial crisis to increase public investment, and the empirical results showed the investment expenditure multiplier was approximately 1.94 and 314,826 jobs were created.

When investment reaches the limit of the economies of scale, R and D is an effective way for overcoming the economic limits. Engaging in R and D to create economies of scale is an effective approach employed in Taiwan to overcome economic difficulties. The scope of R and D is diverse, and relevant studies have adopted diverse perspectives in examining the issue. Based on the stage of development, R and D can be divided into the following stages: Basic research, applied research, development, demonstration, buy-down, and deployment. Specifically, the first three stages are R and D and the latter three stages are in the field of marketing. Additionally, R and D is regarded as technology push and marketing as demand pull. In other words, R and D should be reviewed using an overall chain-linked model (Kline, 1990). R and D must undergo a learning process (Rosenberg, 1976; 1982), where the experience of learning can yield novel methods (learning by searching) and enhance efficiency (learning by doing; learning by using). The knowledge accumulated over an extended period can create benefits for research institutes (Mansfield, 1980).

Furthermore, the information exchange between R and D staffers and people with market demands can yield unexpected discoveries (learning by interacting). In other words, because the technology creation resulting from R and D must match market demands, governments must build a supply-demand formation mechanism before implementing technology-related policies to effectively improve R and D results (Margolis, 2002).

Additionally, building a R and D mechanism can not only yield more efficient economic results but also induce social progress, ultimately achieving a symbiotic evolution of technology and society. When technological advances boost industrial development, a favorable social environment is created (Elzen et al., 2004). This environment can only be achieved by promoting energy technology R and D and appropriate industrial development. Hence, numerous studies have contended the necessity of including R and D as a perspective in environmental policy-making (Kemp, 1997).

Nevertheless, promoting R and D is difficult because R and D knowledge is public goods, which can result in inefficient resource allocation (Arrow, 1962). Furthermore, the influence of R and D on future research results is uncertain and irreversible. Consequently, the process of promoting R and D can be marred with numerous obstacles (Dixit and Pindyck, 1994). Empirical studies on R and D equipment investment and the uncertainty of R and D include Pindyck and Solimano (1993), Ferderer (1993), and Huizinga (1993). Considering the uncertainty and irreversibility of R and D, particular scholars have proposed that R and D should be handled by governments (Lichtenberg, 1989). Empirical results obtained by Levy and Terleckyj (1983) indicated the primary effect of government R and D is that government-commissioned research can induce private investment. Carmichael (1981) also shared this view. Lichtenberg (1984) revealed partial positive effects on inducing private investment. Mamuneas and Nadiri (1996) analyzed the direct effects of government R and D investment and the indirect effect this investment has on private investment. The empirical results showed the spillover effects resulting from the technology accumulated through R and D can reduce the costs producing factors of production. Productivity can be increased by combining the R and D results obtained by the public sector and investments made by private enterprises (Cockburn and Henderson, 1997).

Government R and D investment has diverse effects: In addition to the direct rewards of knowledge and economic benefits, government R and D investment can also motivate enterprises and universities to engage in R and D. Furthermore, from the perspective of additionality, government R and D investment can increase R and D investment and induce behavioral additionality, ultimately yielding additional results (Buisseret et al., 1995). Using 17 OECD member countries as the subject of analysis, Guellec and van Pottelsberghe (2000) found every US$1 of R and D subsidy can attract an average of US$1.7 in private R AND D investment.

Regarding energy R and D, research conducted by National Research Council (2001) showed investments in energy technology R and D can yield economic, environmental, and social security benefits. By conducting further analysis on the same issue, Davis and Owens (2001) estimated, by employing a bidding method, that the development of renewable energy technologies in the United States had a market value US$26.3 billion. Regarding the relationship between economic development and energy environment, numerous studies have indicated economic growth resulted in increased energy consumption (Khobai and Le Roux, 2017; Abidin et al., 2015; Dritsaki and Dritsaki, 2014; Alege et al., 2016; Keho, 2017; Tang et al., 2016; Ozturk, 2010). However, particular scholars have contended energy consumption was not necessarily proportional to gross domestic product growth (Fallahi, 2011). Costanza (1980) used government spending and the household sector as two endogenous variables to estimate energy consumption induced by the production of a unit of commodity.

Among studies that employed the input-output model to analyze the relationship between environment and energy consumption, Kagawa and Inamura (2001) analyzed why the energy consumption in Japan must undergo structural changes and examined structural changes in the energy input of Japan. Particular studies have divided the factors of energy consumption (Hunt and Ninomiya, 2005). Hunt and Ninomiya (2005) used econometric models to investigate why energy demand has changed and used the time series of energy demand to estimate the future energy demand and CO_2 emissions of Japan.

Simultaneously, scholars have examined environmental issues occurring as the Chinese economy developed. For example, Fan et al. (2007) used data in 1997 as a baseline to estimate the energy consumption and CO_2 emissions in China in 2020.

3. EMPIRICAL MODEL

3.1. Dynamic Industry-related Model

To estimate CO_2 emissions and the economic effects of R and D investment, we developed a dynamic industry-related model, where consumption (C) and investment (K) were used as two endogenous variables. 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:

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

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

$$y(t) = V^\tau \bullet X(t) \quad (2)$$

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

$$C^p = H_c \bullet c \bullet y(t) = H_c \bullet c \bullet V^\tau \bullet X(t) \quad (3)$$

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

$$X(t+1) = [K^{-1}(I-A-C) + I]X(t) \quad (4)$$

$$C = C^p + C^G;\ K = k^p + k^G$$

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. k^p and k^G are the investment coefficient matrixes of the private and government sectors, respectively, as shown in the following equations:

$$k^p = \begin{pmatrix} k^p{}_{11} & \cdots & k^p{}_{1n} \\ \vdots & \ddots & \vdots \\ k^p{}_{m1} & \cdots & k^p{}_{mn} \end{pmatrix},\ k^G = \begin{pmatrix} k^G{}_{11} & \cdots & k^G{}_{1n} \\ \vdots & \ddots & \vdots \\ k^G{}_{m1} & \cdots & k^G{}_{mn} \end{pmatrix}$$

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

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

$$X(t+1) = (K^{-1}D + I)X(t) \quad (5)$$

In this study, we adopted an industry-related model featuring open competition.

$X(t) = \left[I - A\left(I-\bar{M}\right)\right]^{-1}\left[E + \left(I-\bar{M}\right)F^d\right]$. Therefore, the dynamic industry-related model is

$$X(t+1) = \left(K^{-1}D + I\right)\left[I - A\left(I-\bar{M}\right)\right]^{-1}\left[E + \left(I-\bar{M}\right)F^d\right] \quad (6)$$

When estimating the intrinsic value and intrinsic vector of $(K^{-1}D + I)$ in (6), let η be the intrinsic value of $D^{-1}K$ and the intrinsic vector be τ:

$$D^{-1}K\tau = \eta\tau \quad (7)$$

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

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

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

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

3.2. Dynamic Environmental Industry-related Model

$$X(t+1) = \hat{E}\left(K^{-1}D + I\right)\left[I - A\left(I-\bar{M}\right)\right]^{-1}\left[E + \left(I-\bar{M}\right)F^d\right] \quad (8)$$

Where the emissions coefficient $e_j = {CO_2}_j / x_j$, and $\hat{E}$ is the diagonal matrix of the elements of the emissions coefficients for various industries.

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

4. EMPIRICAL RESULTS

The empirical results presented in this section were obtained using an investment of NT$100 billion as the baseline of estimation. We divided the industries into seven categories to summarize the differing characteristics of the industries.

Results presented in previous paragraphs show that investment yields numerous economic benefits. However, the consequent CO_2 emissions remain an issue discussed extensively during the process of economic development. Table 1 shows the CO_2 emissions resulting from investments in six major sectors. Overall, government R and D investment resulted in 793,204.70 tons of CO_2 emissions, which was 69.46% of the 1,141,991.12 tons resulting from private investment. The CO_2 emissions of the energy sector was the most significant whether it be government R and D investment or private equipment investment, accounting for 67.86% and 76.31% of the overall emissions, respectively. The two types of investments did not differ substantially in the CO_2 emissions of the industrial sector. However, compared with private investment, government R and D investment resulted in a higher level of CO_2 emissions in the transport sector.

Differing from the categorization of six industry sectors, government R and D investment and private investment also resulted in differing CO_2 emissions in the seven major sectors. Table 8 shows the CO_2 emissions spillover effects of government R and D investment on various industries. Specifically, the CO_2 emissions resulting from raw material induction was 270,751.85 tons, the most of which was emitted by chemistry-related industries (approximately 132,643.62 tons, accounting for approximately 49%). However, the most significant CO_2 emissions resulting from the first spillover was by the infrastructure industries, which amounted to 174,604.01 tons (Table 2).

The CO_2 emissions of agriculture-related industries, the light industries, and the ferrous and non-ferrous metal industries decreased primarily because the first economic spillover effects declined. As shown in Table 2, the CO_2 emissions resulting from government R and D investment were most significant in chemistry-related and infrastructure industries, accounting for 42.05% and 24.58% of the total, respectively. Therefore, the rankings of CO_2 emissions by industry and economic spillover effect by industry differ.

Table 3 shows the energy consumption resulting from R and D investment in energy technologies, the most significant being the energy sector (1,707,151.89 kl of oil equivalent). By contrast, the energy consumption of the household sector decreased by 31,668.86 kl of oil equivalent.

Table 4 shows the CO_2 emissions resulting from private investment in electronics-related industries. Specifically, machinery-related industries yielded the most significant CO_2 emissions in raw material induction, the amount being 155,975.30 tones. Among the CO_2 emissions resulting from the total spillover, the infrastructure industries yielded the most significant CO_2 emissions, which was 690,886.12 tones, accounting for 60.5% of the total emissions. It is worth noting that the CO_2 emissions of agriculture-related industries decreased by 23,978.27 tones because the CO_2 emissions resulting from the first spillover decreased by 37,389.64 tons.

Table 5 shows the energy consumption of the six major industries of private investment. Specifically, the energy sector exhibited the

Table 1: CO_2 emissions of investments in sectors

Industry	Energy	Industry	Transportation	Agriculture	Service	Residence	total
Government R and D investment	538,271.32	118,185.40	134,690.79	22.95	14,243.99	−12,209.75	793,204.70
Percentage	67.86	14.90	16.98	0.00	1.80	−1.54	100.00
Private investment	871,465.86	190,059.23	52,136.03	−721.48	46,425.54	−17,374.07	1,141,991.12
Percentage	76.31	16.64	4.57	−0.06	4.07	−1.52	100.00
A/B	61.77	62.18	258.34	−3.18	30.68	70.28	69.46

Unit: Tons. R and D: Research and development

Table 2: CO_2 emissions of government R and D investment

Sector	Raw material induced value	First spillover effects	Second spillover effects	Total	Percent
Agriculture-related	613.96	−9243.86	18,534.05	9904.14	1.25
Light industry	2916.81	−682.69	2575.46	4809.58	0.61
Chemical-related	132,643.62	157,843.47	43,061.97	333,549.06	42.05
Iron, non-iron	4749.83	−2880.51	612.52	2481.83	0.31
Machinery-related	60,770.55	27,439.04	17,710.98	105,920.57	13.35
Infrastructure	19,807.35	174,604.01	564.47	194,975.84	24.58
Service-related	49,249.73	53,504.49	38,809.46	141,563.68	17.85
Total	270,751.85	400,583.94	121,868.91	793,204.70	100

Unit: Tons. R and D: Research and development

Table 3: Energy consumption resulting from government R and D investment

Energy	Industry	Transportation	Agriculture	Service	Residence	total
1,707,151.89	227,484.49	205,150.88	883.81	42,300.71	−31,668.9	2,151,302.91

Unit: kl of oil equivalent. R and D: Research and development

Table 4: CO_2 emissions of private investment

Sector	Raw material induced effects	First spillover effects	Second spillover effects	Total	Percent
Agriculture-related	332.04	−37,389.64	13,079.34	−23,978.27	−2.10
Light industry	1708.56	−275.49	1,817.48	3250.54	0.28
Chemical-related	84,494.45	116,186.73	30,388.49	231,069.67	20.23
Iron, non-iron	8060.98	−4335.89	432.3	4157.39	0.36
Machinery-related	155,975.30	12,652.78	12,498.64	181,126.73	15.86
Infrastructure	18,334.77	672,153.13	398.22	690,886.12	60.50
Service-related	23,704.21	4,386.61	27,388.12	55,478.94	4.86
Total	292,610.31	763,378.22	86,002.58	1,141,991.12	100

Unit: Tons

Table 5: Energy consumption of private investment

Energy	Industry	Transportation	Agriculture	Service	Residence	Total
1,546,365.06	257,668.8	79,409.68	−2069.09	8625.79	−45,063.7	1,864,936.46

Unit: kl of oil equivalent

highest energy consumption and the agriculture and residential sectors exhibited decreased energy consumption.

5. CONCLUDING REMARKS

In addition to boosting economic growth, government R and D investment and private equipment investment can reduce CO_2 emissions. The effects of economic growth involve crude 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, further driving economic growth and reducing CO_2 emissions.

The CO_2 emissions resulting from private equipment investment were higher (1.44 times) than those resulting from government R and D investment. Generally speaking, CO_2 emissions is determined by the size of economic activities and CO_2 emissions coefficient. Part of private equipment investment is spent on equipment upgrading. Although new-technology equipment might reduce CO_2 emissions, the novel technologies might improve productivity and competitiveness, ultimately increasing yield and indirectly increasing CO_2 emissions. In the case of government R and D investment, industry growth might also increase CO_2 emissions. Nevertheless, government investment had the greatest economic spillover effect on service-related industries, where the emissions coefficient and CO_2 emissions are lower than those of other industries.

After further analyzing the empirical results stated in previous paragraphs, we divided the industries into four types based on the size of economic spillover and CO_2 emissions. The categorization enabled us to develop objective evaluations of the effects of government and private investments. The four types are strong economic effect-high emissions coefficient, weak economic effect-high emissions coefficient, weak economic effect-low emissions coefficient, and strong economic effect-low emissions coefficient, as shown in the following paragraphs.

Type I is strong economic effect-high emissions coefficient industries, which primarily include chemistry-related and infrastructure industries. Representative industries in the quadrant include plastics (synthetic resin), synthetic rubber, gas, and refined petroleum products. These industries involve intermediate goods necessary for producing raw materials or the fuel necessary for production. To achieve Taiwanese economic growth, these industries are vital sectors that cannot be removed at this stage. Consequently, CO_2 emissions remain high.

Type II is weak economic effect-high emissions coefficient industries, which primarily include chemistry-related industries. These industries are not the core industries driving economic growth, and a significant proportion of these industries have moved overseas or rely on importation. The representative industries of Type II are coke and other coal products, other man-made fibers, cleaning supplies, and cosmetics. The majority of these industries are encountering problems with restructuring. A necessary practice for achieving sustainable business is to improve productivity or value added by engaging in R and D.

Type III is weak economic effect-low emissions coefficient industries, which primarily include agriculture-related and light industries. Agriculture was a vital contributor to the economic miracle in Taiwan in terms of foreign exchange acquisition and cheap labor supply. As industry structures evolved, agriculture no longer acts as a vital booster of economic development; instead, it became a crucial leading force in environmental preservation. Representative industries of Type III include agriculture-related industries, other horticultural crops, animal products, and forest products.

Type IV is strong economic effect-low emissions coefficient industries, primarily including machinery- and service-related industries. These industries are the main forces driving the economic development in Taiwan. Specifically, machinery-related industries are high-technology industries, which the government has been actively promoting since the 1970s. Currently, these industries have become the dominant industries of the Taiwanese economy. Service-related industries are the main industries on which domestic demand expansion relies. Representative industries of Type IV include semiconductors, passive electronic components, circuit board for printing, photoelectric materials and components, financial intermediation, and healthcare services. Compared with industries in the first quadrant, these industries yielded significantly lower CO_2 emissions coefficients and considerably reduced CO_2 emissions.

In conclusion, the economic development and environmental maintenance in Taiwan can be achieved by engaging industrial restructuring. The success of the restructuring hinges on R and D and equipment investment. We can conclude that investment is essential food for realizing economic growth, and R and D is the leaven of economic development.

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