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

Chung-Huang Huang , Taiwan Research Institute & Taiwan Association of Environmental and Resource Economics, Taiwan
Cheng-Yih Hong, Chaoyang University of Technology, Taiwan
Han-Pang Su, Taiwan Research Institute, Taiwan
Chin-Wen Yang, Taiwan Research Institute, Taiwan
Jian-Fa Li, Chaoyang University of Technology, Taiwan

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Abstract
Taiwan has exposed the vulnerability of its economy during the 2008 financial crisis. The issues on democratization, the rise of citizen's consciousness and environmental protection have received well attention. The symbiosis of economic activity and environment has failed to meet current needs. We combine the Habitat Segregation Theory and the Spiral Pattern of Economic Development to serve as a mode of the co-evolution of economic activities and environment. Furthermore, this study employs a dynamic industry-related model to estimate the economic spillover effect and the CO2 emissions from both R&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 (1) the investment multiplier of government R&D and private equipment investment, (2) the difference in the employment creation effect of government R&D and private equipment investment and (3) The CO2 emission of both governmental R&D and private equipment investment, and further to propose the direction of Taiwan's industrial development.

Keywords: Government R&D Investment, Private Equipment Investment CO_2 Emission Coefficient, Dynamic Industry-Related Model

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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. 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 six-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.

Numerous studies have shown that energy price fluctuations can cause tremendous economic loss when economic growth hinges excessively on energy consumption (Bruno & Sachs, 1985; Hamilton, 1983 & 1996; Davis and Haltiwanger, 2001; Lee and Ni, 2002). 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 and 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 research and development (R&D) is imperative for maintaining competitiveness in high technology industries. Effective R&D can boost productivity and create added values. Improved productivity can increase profits by reducing energy consumption while achieving the objective of environmental preservation. Furthermore, added value creation can increase the R&D funding of businesses, thereby achieving industry upgrading, which can yield more mature economic constitution and ultimately achieve sustainable economic development. Although energy prices and demands are asymmetrical (Fan et al., 2007; Ma et al., 2008; Roy et al., 2006), R&D-enabled technological advances can reduce energy demands (Dowlatabadi et al., 2006; Boone et al.,1996). By dividing productivity of the energy sector into efficiency and technical changes, Kumar et al. (2009) analyzed the relationship between technological advances in R&D and energy price fluctuations.

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 energy saving technologies and energy efficiency, which enable a country to adapt to changes in the international economic environment and realize industrial restructuring.

Achieving industrial restructuring by engaging in high technology R&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&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&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&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&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.

The dynamic industry-related model was employed to estimate the economic spillover effects and CO_2 emissions of various industries. Subsequently, we compared the results with the economic benefits and CO_2 emissions of various industries to analyze the current industrial development in Taiwan.

Literature Review

The literature on investment is focused heavily on the influence of government public spending on economy (Roller and Waverman, 2001; Romp and de Haan, 2005; Heintz et al, 2009; Reinhart & Rogoff, 2009; Fishback and Valentina, 2010; Ramey, 2011; Parker, 2011; Hong and Li, 2015). Ramey (2011) estimated that the temporary investment multiplier devised by the U.S. government was between 0.5 and 2.0. Fishback and Valentina (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&D is an effective way for overcoming the economic limits. Engaging in R&D to create economies of scale is an effective approach employed in Taiwan to overcome economic difficulties. The scope of R&D is diverse, and relevant studies have adopted diverse perspectives in examining the issue. Based on the stage of development, R&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&D and the latter three stages are in the field of marketing. Additionally, R&D is regarded as technology push and marketing as demand pull. In other words, R&D should be reviewed using an overall chain-linked model (Rothwell, 1977 and 1994; Rothwell & Gardiner, 1985; kline, 1990). R&D must undergo a learning process (Rosenberg, 1976, 1982; Lundvall, 1988 and 1992), 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 (Terleckyj, 1974; Griliches, 1979; Mansfield, 1980). Furthermore, the information exchange between R&D staffers and people with market demands can yield unexpected discoveries (learning by interacting). In other words, because the technology creation resulting from R&D must match market demands, governments must build a supply-demand formation mechanism before implementing technology-related policies to effectively improve R&D results (Margolis and Kammen, 1999; Banales-Lopez and Norberg-Bohm, 2002; Margolis, 2002).

Additionally, building a R&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 (Nelson and Winter, 1982; Hughes, 1983; Elzen et al., 2004). This environment can only be achieved by promoting energy technology R&D and appropriate industrial development. Hence, numerous studies have contended the necessity of including R&D as a perspective in environmental policy-making (Heaton and George, 1990; Wallace, 1995; Banks and Heaton, 1995; Kemp, 1997; Hemmelskamp, 1997).

Nevertheless, promoting R&D is difficult because R&D knowledge is public goods, which can result in inefficient resource allocation (Arrow, 1962). Furthermore, the influence of R&D on future research results is uncertain and irreversible. Consequently, the process of promoting R&D can be marred with numerous obstacles (McDonald and Siegel, 1986; Bertola, 1988; Pindyck, 1988; Dixit and Pindyck, 1994). Empirical studies on R&D equipment investment and the uncertainty of R&D include Pindyck and Solimano (1993), Ferderer (1993), and Huizinga (1993). Considering the uncertainty and irreversibility of R&D, particular scholars have proposed that R&D

should be handled by governments (Carmichael, 1981; Lichtenberg, 1984). Empirical results obtained by Levy and Terleckyj (1983) indicated the primary effect of government R&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&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&D can reduce the costs producing factors of production. Productivity can be increased by combining the R&D results obtained by the public sector and investments made by private enterprises (Cockburn-Henderson, 1997).

Government R&D investment has diverse effects: In addition to the direct rewards of knowledge and economic benefits, government R&D investment can also motivate enterprises and universities to engage in R&D. Furthermore, from the perspective of additionality, government R&D investment can increase R&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 Pottelsberghe (2000) found every US$1 of R&D subsidy can attract an average of US$1.7 in private R&D investment.

Regarding energy R&D, research conducted by National Research Council (2001) showed investments in energy technology R&D can yield economic, environmental, and social security benefits. By conducting further analysis on the same issue, Davis & Owens (2003) 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. However, particular scholars have contended energy consumption was not necessarily proportional to GDP growth (Costanza, 1980; Costanza and Herendeen, 1984; Fallahi, 2011; Lee, 2006). Costanza (1980) and Costanza and Herendeen (1984) 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 (2000) 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 (Kagawa and Inamura, 2000; Hunt and Ninomiya, 2005; IEEJ, 2011). 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, Ying Fan et al. (2007) used data in 1997 as a baseline to estimate the energy consumption and CO_2 emissions in China in 2020. Liu et al. (2010) further adopted a trade perspective to analyze the energy consumption in China.

Empirical Model

To estimate CO_2 emissions and the economic effects of R&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:

$$\boldsymbol{X(t) = AX(t) + C^p + C^G + K[X(t+1) - X(t)]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(1)}$$

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

$$\boldsymbol{y(t) = V^t \cdot X(t)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(2)}$$

$\boldsymbol{V^t}$ is the vector of the value-added rate.

$$\boldsymbol{C^p = H_c \cdot c \cdot y(t) =}$$
$$\boldsymbol{H_c \cdot c \cdot V^t \cdot X(t)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3)}$$

$\boldsymbol{c}$ is the consumption rate, and $\boldsymbol{H_c}$ is the vector of consumption patterns.

$$\boldsymbol{X(t) = AX(t) + (C^p + C^G)X(t) + (k^p + k^G)[X(t+1) - X(t)]}$$
$$\boldsymbol{X(t+1) = [K^{-1}(I - A - C) + I]X(t)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(4)}$$
$$\boldsymbol{C = C^p + C^G} \quad ; \boldsymbol{K = k^p + k^G},$$

where $\boldsymbol{C^p}$ is private sector consumption and $\boldsymbol{C^G}$ is government sector consumption; $\boldsymbol{k^p}$ is private sector investment and $\boldsymbol{k^G}$ is government sector investment. $\boldsymbol{k^p}$and $\boldsymbol{k^G}$ are the investment coefficient matrixes of the private and government sectors, respectively, as shown in the following equations:

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

Specifically, the scale of government consumption ($\boldsymbol{C^G}$) is determined by budgetary planning. Therefore, $\boldsymbol{C = H_c \cdot c \cdot V^t \cdot X(t) + C^G.}$
Assuming $\mathrm{D} = \boldsymbol{I - A - C}$, the dynamic model can be written as

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

In this study, we adopted an industry-related model featuring open competition. $\boldsymbol{X(t) = [I - A(I - \bar{M})]^{-1}\left[E + (I - \bar{M})F^d\right]}$. Therefore, the dynamic industry-related model **is**

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

When estimating the intrinsic value and intrinsic vector of $\boldsymbol{(K^{-1}D + I)}$ in (6), let $\boldsymbol{\eta}$ be the intrinsic value of $\mathbf{D}^{-1}\boldsymbol{K}$ and the intrinsic vector be $\boldsymbol{\tau}$:

$$\boldsymbol{D^{-1}K\tau = \eta\tau} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(7)}$$
$$\boldsymbol{\frac{1}{\eta}(K^{-1}D)(D^{-1}K)\tau = K^{-1}D\tau}$$
$$\boldsymbol{\frac{1}{\eta}\tau = K^{-1}D\tau}$$
$$\boldsymbol{(K^{-1}D + I)\tau = (\frac{1}{\eta} + 1)\tau}$$

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

Dynamic Environmental Industry-related Model

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

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.

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

Empirical Results

The empirical results presented in this section were obtained using an investment of NT$100 billion as the baseline of estimation. We analyzed the economic spillover effects of government R&D investment and private equipment investment as well as the number of jobs created. We divided the industries into seven categories to summarize the differing characteristics of the industries.

Economic Spillover Effect of R&D Investment

Economic Spillover Effects

Table 1 shows the production induced, crude value-added, and income from employment resulting from government R&D investment. Specifically, the economic spillover was NT$140.472 billion, NT$69.472 billion, and NT$39.378 billion, respectively; and the investment multiplier was 1.4. In addition, the economies of scaled induced in the first and second spillover was approximately NT$40 billion.

Table 1 The Economic Effects from Government R&D Investment

	Production Induced Value	Gross Induced Added Value	Induced Income of Employment
Direct Spillover Effects	100	57.64	32.340
First Spillover Effects	28.417	7.666	0.459
Second Spillover Effects	12.056	4.167	2.579
Total Spillover Effects	140.472	69.472	39.378
Multiplier	1.40		

Note: Unit: billion New Taiwanese dollars.

Using the electronics industry as a subject, the economic effect of equipment investment is shown in Table 2. Specifically, the economic effect of private investment was significantly weaker than that of government R&D investment.

Specifically, the production induced, crude value-added, and income from employment resulting from private investment were NT$107.315 billion, NT%14.457 billion, and NT$10.950 billion, respectively; and the investment multiplier was 1.07. In other words, the economic effect of government investment was stronger than that of private investment. Specifically, the production induced, crude value-added, and income from employment associated with private investment was 1.31, 4.81, and 3.60 times that of government investment, respectively. The differences in the economic spillover effects of private and government investments exist because the direct economic effect of government investment is stronger than that of private enterprises. This is because electronics manufacturing relies heavily on importation; consequently, the investment multipliers differed.

Table 2 The Economic Effects from the investment on electronics industry

	Production Induced value	Gross Induced Added Value	Induced Income of Employment
Direct Spillover Effects	64.492	7.186	4.904
First Spillover Effects	34.316	4.331	4.225
Second Spillover Effects	8.508	2.94	1.82
Total Spillover Effects	107.315	14.457	10.95
Multiplier	1.07		

Note: Unit: billion New Taiwanese dollars.

Furthermore, private investment resulted in less satisfactory crude value-added and income from employment primarily because the electronics sector exhibited less satisfactory crude value-added and income from employment compared with that resulting from relevant sectors handling government R&D.

As shown in Table 3, government R&D investment created more jobs than private investment, the numbers being 29,400 and 20,872, respectively. A further observation of the number of jobs created in raw materials industries as a result of the two economic spillovers showed that government investment had stronger effects than private equipment investment, with a difference of 8,528 jobs. This is primarily because the electronics sector has less impact on service-related industries and is thus unable to provide considerable job opportunities. This issue will be further elaborated in a subsequent paragraph.

Table 3 Employment Creation

	Raw Material Induced Value	First Spillover Effects	Second Spillover Effects	Total
Government R&D investment	13,439	10,058	5,903	29,400
private Equipment	10,258	6,448	4,166	20,872

Investments				
Difference in Employment	3,181	3,610	1,737	8,528

Note: Unit: Persons.

Economic Spillover Effects for Industries

Based on the nature of the industries, we divided the 166 sectors listed in The Report on 2011 Input-Output Tables into seven major industries. Table 4 shows the economic effects of government 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.

Table 4 Economic Effect of Government R&D Investment

Sector	Raw Material Induced Value	First Spillover Effects	Second Spillover Effects	Total	Percentage
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%

Note: Million New Taiwanese Dollars

Regarding the economic effects of private equipment investment on various industries, private investment had the most significant economic spillover effects on machinery-related industries and the infrastructure industries, as shown in Table 5. 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. However, compared with government R&D investment, private investment had a greater effect on raw material induction. In addition to increasing the quantity of machinery appliances, private equipment investment accounted for 26.77% of the economic effects on the infrastructure industries. Increasing investment in the infrastructure industries mean that private equipment investment and production will affect sectors such as plant construction, power demand, waste disposal and recycling, and pollution remediation.

Table 5 Economic Spillover Effects of Private Equipment Investment

Sector	Raw Material Induced Value	First Spillover Effects	Second Spillover Effects	Total	Percent (%)
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

Note: Million New Taiwanese Dollars

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

Test 6 Employment Creation on Industries

	Government R&D Investment		Private Equipment Investment		Difference in Number of Employment (person)
	Employment Creation (persons)	Coefficient of Employment (persons per million dollars)	Employment Creation (person)	Coefficient of Employment(Person per million)	
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,	402	0.58	603	0.52	-201

Non-Iron					
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

Estimations regarding the number of jobs created in various industries by government R&D investment and private equipment investment are shown in Table 6. Although the economic spillover effect of government 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 private electronics 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 government R&D investment and private investment was most significant in service-related industries, with a difference of 7,582 jobs. However, compared with government 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 government R&D investment and private investment differed in employment multiplier. Overall, the employment multiplier of government R&D investment was 0.35 jobs per NT$1 million whereas that of private investment was 0.21 jobs per NT$1 million. Except for the employment multiplier in agriculture-related industries, the employment multipliers resulting from government R&D investment were all greater than those resulting from private investment. This result indicates that the employment effect of R&D investment was superior to that of private investment in high technology equipment.

Energy consumption and CO_2 emissions resulting from government R&D investment and private equipment investment

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 7 shows the CO_2 emissions resulting from investments in six major sectors. Overall, government R&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&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&D investment resulted in a higher level of CO_2 emissions in the transport sector.

Table 7 CO_2 Emissions of investments in Sectors

Industry	Energy	Industry	Transportation	Agriculture	Service	Residence	total
Government R&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%

Note: Unit: tons

Differing from the categorization of six industry sectors, government R&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&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.

Test 8 CO_2 emissions of Government R&D investment

sector	Raw Material Induced Value	First Spillover Effects	Second Spillover Effects	Total	Percent (%)
Agriculture-related	613.96	-9,243.86	18,534.05	9,904.14	1.25
Light Industry	2,916.81	-682.69	2,575.46	4,809.58	0.61
Chemical-related	132,643.62	157,843.47	43,061.97	333,549.06	42.05
Iron, Non-Iron	4,749.83	-2,880.51	612.52	2,481.83	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

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 8, the CO_2 emissions resulting from government R&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 9 Energy consumption resulting from Government R&D investment

Energy	Industry	Transportation	Agriculture	Service	Residence	total
1,707,151.89	227,484.49	205,150.88	883.81	42,300.71	-31,668.86	2,151,302.91

Table 9 shows the energy consumption resulting from R&D investment in energy technologies, the most significant being the energy sector (1,707,151.89 kiloliters of oil equivalent). By contrast, the energy consumption of the household sector decreased by 31,668.86 kiloliters of oil equivalent.

Table 10 CO_2 Emissions of Private Investment

sector	Raw Material Induced Value	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	1,708.56	-275.49	1,817.48	3,250.54	0.28
Chemical-related	84,494.45	116,186.73	30,388.49	231,069.67	20.23
Iron, Non-Iron	8,060.98	-4,335.89	432.3	4,157.39	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

Table 10 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 11 Energy Consumption of Private Investment

Energy	Industry	Transportation	Agriculture	Service	Residence	total
1,546,365.06	257,668.75	79,409.68	-2,069.09	8,625.79	-45,063.73	1,864,936.46

Table 11 shows the energy consumption of the six major industries of private investment. Specifically, the energy sector exhibited the highest energy consumption and the agriculture and residential sectors exhibited decreased energy consumption.

Concluding Remarks

In addition to boosting economic growth, government R&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. Crude 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. Furthermore, increased income from employment and job opportunities can improve spending power, ultimately increasing market demands. The following paragraphs present the empirical results obtained in this study:

(1)The investment multiplier of government was 1.40, which was greater than that of private 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, government 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, private 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 private investment was not comparable to that of government R&D investment.
(2) Government R&D investment created the most job opportunities in service-related industries, whereas private investment created the most job opportunities in machinery-related industries. Overall, government 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 government 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) The CO_2 emissions resulting from private equipment investment were higher (1.44 times) than those resulting from government R&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&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&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&D and equipment investment. We can conclude that investment is essential food for realizing economic growth, and R&D is the leaven of economic development.

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