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A dynamic general equilibrium model for public R&D investment in Taiwan

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ABSTRACT

In terms of economic development policies, public research and development (R&D) investment may be one of the most critical and useful tools in Taiwan, having frequently played a role in leading related overall investment in Taiwan. Although the impact channels of R&D investment are varied and complex, its benefits in terms of the development of human capital, industrial productivity, and basic research are clear. With the rapid growth of the private sector in the Taiwan economy, it is, however, debatable whether the government should continue to use the public financial budget to invest in R&D. By using a computable general equilibrium (CGE) model to simulate the impact of public R&D investment on the economy in Taiwan, the empirical evidence of the present paper is that public R&D investment gives rise to different short-term and medium-term impacts on real GDP that are mostly felt in the third or fourth years of their implementation among different industries. These impacts then gradually converge back to equilibrium in the long run. Public R&D investment boosts the technology of high-tech industries and increases exports, but it also crowds out the output of primary industries. Although the public R&D investment has a positive effect on the real wage, its effect on inflation should not be overlooked. Because of the pros and cons surrounding the impact of public R&D investment on industries and the economy, the study provided by the present paper can serve as valuable reference not only to decision-makers in government agencies but also to academic researchers.

1. Introduction

Investment in the research and development (R&D) of science and technology is considered to be one of the key criteria for evaluating the economic development and competitiveness of a nation. It affects economic growth through multiple channels such as innovation, capital accumulation, and human resource development, all of which gradually lead to the overall development of the economy. In Taiwan, the government has played a leading role in investing in science and technology R&D, or public-funded R&D investment, and, consequently, how to effectively evaluate the economic benefits of the public R&D investment has become a major concern of the incumbent government.

Technological advances have since 1980 been playing a key role in promoting economic growth and the innovation of science and technology, and many countries have been marking up their R&D investment to boost their economic growth and national competitiveness. As a consequence, government input has become an important approach to strengthening the R&D of selective sciences and technologies and the subsequent industrial development. Take Finland for example. Finland was ranked third in the world according to the 2005–2006 World Competitiveness Yearbook (www.weforum.org/gcr), and its success was partly reflected in the fact that R&D human resources accounted for 2.4% of its employed population, which was much higher than the 1.7% for Sweden and the 0.44% for the European Union average. The same fact further indicated the importance of human capital to future economic growth, as evidenced by the study of Griffith et al. (2004), which indicated that human capital mobilized by R&D investment was crucial for innovation and for developing countries to catch up with developed countries.

Generally speaking, R&D investment in science and technology affects economic growth through both direct and indirect channels. The former mainly refers to the purchase and consumption of domestically produced products under the government budget, while the latter includes: (1) a reduction in production costs, which leads to higher market competitiveness; (2) an improvement in the labor productivity of the producer, thus generating more revenue and value added; and (3) the creation of a spillover effect, which generates higher production value and value added through the industrial correlation effect. However, to evaluate the impact of public R&D investment on the overall economy is a complex and subtle task,[1] and

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[1] Any attempt to simulate all the direct and indirect channels which affect the economic growth in a single model is a tall order. The major difficulties are the indefinite theory and nearly invisible human capital and R&D investment field data. Therefore, it is definitely not the ambition of the present paper to cover everything once and for all.

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there is a need for a comprehensive macro-economic input–output framework or a computable general equilibrium (CGE) system model. Although there are vast numbers of CGE studies in the literature, CGE studies that focus on R&D investment are few, which may be because of the difficulties associated with handling capital investment data and R&D model construction.

In the present paper, a dynamic CGE model (SciBud-CGE) is constructed for the purpose of analyzing the impact of R&D investment by using a government scientific budget. This SciBud-CGE model was expanded on the basis of the ORANI-RD (recursive dynamic) model developed by Monash University. The ORANI model was first developed in the 1970s by Dixon et al. (1977) under the IMPACT project sponsored by the Australian government. ORANI-G, a simplified version of the ORANI model, is a suitable choice for developing a static general equilibrium model for other economies. The ORANI-RD model is a dynamic version of the ORANI-G model that employs a recursive dynamic method to find solutions. Consequently, ORANI-RD has been chosen in this study as the platform for developing a dynamic SciBud-CGE model so as to investigate the macro-economic effects of the public R&D input.

This paper is divided into six sections. Besides Section 1's Introduction, Section 2 briefly reviews previous research on the economic modeling of R&D investment. Section 3 describes the dynamic general equilibrium model for public R&D investment, namely, the SciBud-CGE model that is used in this study. Section 4 elaborates on the data structure used in the SciBud-CGE model and analyzes the processing of the data on public R&D investment. Section 5 covers the results of the shock analysis in relation to public R&D investment and the forecast of changes in the macro economy and industrial structure over the next ten years. Finally, Section 6 presents the conclusions and remarks of this study.

2. Previous research

There are basically two major types of empirical economic modeling related to the study of R&D investment and its impact on economic growth. The first and more commonly seen type of model is the econometric model and the second type of model is the CGE model.

2.1. Econometric R&D investment model

Econometric models have been frequently employed to study the positioning of government R&D investment and its impact. Andres and Benat (2004) found that the long-term effect of public R&D on productivity was positive but insignificant, with a coefficient of elasticity of 0.012 between the two variables. Archibald and Pereria (2003) took the 1956–1988 yearly data in the US and incorporated the five variables of public R&D investment, private R&D investment, private sector investment, employment, and total output of the private sector, to construct a vector-auto-regressive (VAR) model. From an unexpected one-time shock simulation, their study indicated that public R&D input in the long-term would not affect employment but would induce more investment and R&D input from the private sector. That is to say, 1 US dollar of public R&D input in the long-term would induce 1.49 dollars of private sector investment, 0.52 dollars of private R&D input, and 6.99 dollars of total output from the private sector.

Le Bas (2000) employed a macro-economic model to quantify the effect on the economy of addressing the policy of private R&D input, and found that the short-term effect did register with economic growth and the R&D input but that the long-term effect was relatively weak. Comparative analyses across industrial sectors revealed that the elasticity between economic growth and private R&D input was higher in those sectors with higher technological requirements.

Guellec and De La Potterie (2001) employed the 1980–1998 data from major OECD countries to estimate how technological change contributed to multi-factor productivity (MFP) by including three sources of new technological advances, namely, public R&D input, domestic business R&D input, and foreign business R&D input, each of which was analyzed for its effect on output growth in different OECD countries. The research findings indicated that R&D inputs were crucial to productivity and economic growth, and business R&D demonstrated a high spillover effect since it effectively acquired technologies that spilled over from the government and university R&D. The government needed to provide adequate funding for the public R&D, especially higher education, which would have a significant effect on long-term economic growth. The effect of public R&D on productivity depended on the efficiency and capacity of the private sector R&D.

Nadiria and Mamuneas (1994) confirmed the positive effect of public construction and public R&D input on factor productivity in a study that employed a total factor productivity (TFP) model. Their major findings also indicated that the factors contributing to TFP growth varied with industries.

Based on the above references, it can be argued that the public R&D input had a positive effect on economic growth and that its specific effect varied with industries. In empirical studies, however, the results obtained from econometric models are often not based on general equilibrium theory and, therefore, have fallen short of investigating the factors contributing to economic growth or to industrial structural change.

2.2. CGE R&D investment model

Recently, the computable general equilibrium (CGE) model has received much attention in empirical economic research because it links the fundamental production and consumption theories to field data and policy simulation/evaluation. As mentioned above, the difficulty involved in constructing an R&D investment CGE model arises from how to handle capital investment data which are linked to a reasonable R&D investment theoretical model.

Commonly seen typical investment-related CGE studies include Naastepad (2001), which focused on directed credit policy in a Financial CGE model, Nunnenkamp et al. (2007), which dealt with the foreign direct investment (FDI) problem in relation to household welfare, and Piazolo (2001), which discussed the adjustment costs in the private investment sector. However, none of their studies was concerned with the capital R&D investment policy and consequent economic growth CGE modeling work.

Other specific CGE studies with specific reference to the R&D investment model include the following.

Bye et al. (2009) built a Walrasian type of CGE model (please refer to Shoven and Whalley, 1992) that discussed how innovation incentives (e.g., subsidies on R&D, capital formation, or domestic investment) affected Norway's small and open economy. The major finding of their paper is that the introduction of a subsidy policy in relation to domestic investment for different varieties of capital generates less economic growth and welfare than the effects on economic growth and welfare in the case of the other two subsidy policies directed towards R&D and capital formation, although all of the effects on GDP growth rates under the three policies are both positive and small. Bye et al. (2009) is an interesting paper with the standard design of a Walrasian type of CGE model. There is one representative consumer and two representative producers in the economy. One producer is in charge of the production of patents and the other one takes care of final goods. Every capital variety-producing firm buys one patent good from the R&D industry as a sunk establishment cost under the Utopia knowledge market assumption. By imposing subsidy policies as cost reduction conditions and under market cleaning conditions for all goods, they can simulate the effects of an innovation subsidy policy on the economy. The basic problem with their model is the design of the Utopia knowledge market for patent goods. The designed market just does not exist in the real world. In addition, because there is no public finance mechanism inside the model, the government has a very limited function in designing a tax/subsidy policy under such a simplification of the CGE model.

In a US CGE model, Garau and Lecca (2007) divided capital into real capital and knowledge capital, and performed shock analysis on the knowledge capital. The results provided evidence of the existence of short-term positive effects on the employment rate, price index, real salary and economic growth. In the long-term, however, only economic growth remained positively affected, while the effects on other macro-economic factors were approaching zero (i.e., were stabilized). However, in this model, knowledge capital was not econometrically analyzed since the external data of the Yale Technology Matrix (YTM) were used for analysis and the respective percentages of different capital inputs were not estimated by using real industrial data. Therefore, the externally decided spillover effect of technologies led to the same increase in economic growth on a year-on-year basis, which implies that further exploration of the model specification is required.

Giesecke and Madden (2006) employed an Australia CGE model over a forecast period covering 2000–2005, based on the assumptions that the R&D input would induce human resource development and the subsequent increase in labor productivity, that the outcomes of successful R&D would improve factor productivity and industrial development, and that the spillover effect of technologies was derived from the impact on the technological factor variables. Their empirical results indicated that on a year-on-year basis the R&D input induced real consumption, real investment, and economic growth. On the other hand, the R&D input had limited effects on tax revenue growth and no effect at all on employment and prices. From an industrial perspective, it took quite a long time before the effect of the R&D input gradually emerged in the industries concerned. This study has, however, fallen short of clearly defined shock targets; its finding of a zero effect on prices and employment remains disputable. Finally, its finding that the effects of the R&D input were the same across industries, despite the fact that the R&D input level varied with industries, also merits further investigation.

Lin and Hsu (1996) specifically divided Taiwan's public R&D funding into two types. The first type consisted of project-based funding provided to public research organizations that undertook public R&D projects,[2] with the ultimate objective of transferring the outcomes to the businesses concerned, and the other type had to do with the provision of active guidance on new product development through direct funding for private R&D activities. The simulation results in this static CGE model indicated that, with real GDP as the indicator for economic benefits, direct funding to businesses in general was more effective and gave rise to bigger increases in total government revenue than funding to public research organizations. A comparison of different simulations revealed that, with the same R&D investment target of NT$5.6 billion dollars, public funding to R&D foundations generated a 0.03% growth of real GDP, compared to 0.08% GDP growth as a result of direct funding to business R&D activities. In reality, however, public R&D policies may experience a time-lag effect in generating the benefits of a reduction in production costs or productivity improvement, which means that inputs in the current period will not immediately be reflected in output in the same period. Consequently, a dynamic model is required to perform adequate simulation and should be considered in developing a R&D CGE simulation model.

Based on the above references, CGE models may offer a comprehensive macro-economic study that can be used along with input–output tables to create the synergy of theoretical and empirical evidence and perform shock analysis on a public R&D policy. However, the static CGE model is inadequate, such as in Lin and Hsu (1996), because it does not include capital adjustments, and, as a result, the policy simulation has an applicable scope that is smaller than that of econometric models, which can be used for both prediction and policy analyses. Consequently, how to incorporate projection functionality into the model has long been an important objective in the development of CGE models. The rationale for developing a dynamic CGE model is to compensate for the weaknesses of an econometric model so that a dynamic CGE model can use input–output data to investigate the interactions between the government R&D input and changes in various industries and the economy as a whole.

3. Theoretical framework of the SciBud-CGE model

As referred to above, the energy general equilibrium model, SciBud-CGE, is basically revised according to the ORANI-RD model. It features a dynamic single-country general equilibrium model with the function of capital accumulation as its main dynamic mechanism. The SciBud-CGE model coupled with a database (e.g., an Input–output Table in Taiwan) and related parameters (e.g., some of the parameters from the GTAP (2006) database) are used to derive the respective equilibrium values for GDP, employment, the price level, changes in the industrial structure, consumption, investment, and the tax revenue of a single region (in this case, Taiwan) and to perform a simulation and analysis of the public R&D investment policy effects.

3.1. Model specification of SciBud-CGE

The SciBud-CGE model assumes a weak separability[3] for both inputs and outputs and defines production, investment, and consumption behavior in a nest structure format.

3.1.1. Production structure

As shown in Fig. 1, the bottom layer of the nest structure comprises the input factors required for production activities and includes the three primary inputs of land, labor and capital as well as intermediate inputs that are both domestically produced and also imported into the economy. In addition, various attributes of labor can also be aggregated through the constant elasticity of substitution (CES) function. The CES function can be mathematically expressed as follows:

$$Y = A\left[\sum_{i=1}^{n} \delta_i X_i^{-\rho}\right]^{-1/\rho} \quad (1)$$

where Y is the output of production; $X_1, \ldots, X_n$ are input factors; and A, δ, and ρ are parameters that satisfy $\sum_{i=1}^{n} \delta_i = 1$.

The SciBud-CGE model assumes that primary inputs are separable and employs the CES production function to aggregate all factor inputs to obtain an aggregate primary input. That same CES function is

[2] Since 1979, the Ministry of Economic Affairs in Taiwan has been compiling budgets to commission its subordinate R&D organizations, e.g., the Industrial Technology Research Institute, the Chung-Shan Institute for Science and Technology, as well as the Institute for Information Industry, with projects on industry-specific technology R&D.

[3] If a function is separable, then its components can be divided into certain subgroups. The separation criterion is applied to combine all components that are highly correlated in one subgroup. This means that after this grouping process, the marginal substitutive rate of factors in the same group is independent of the rates of all the other groups.

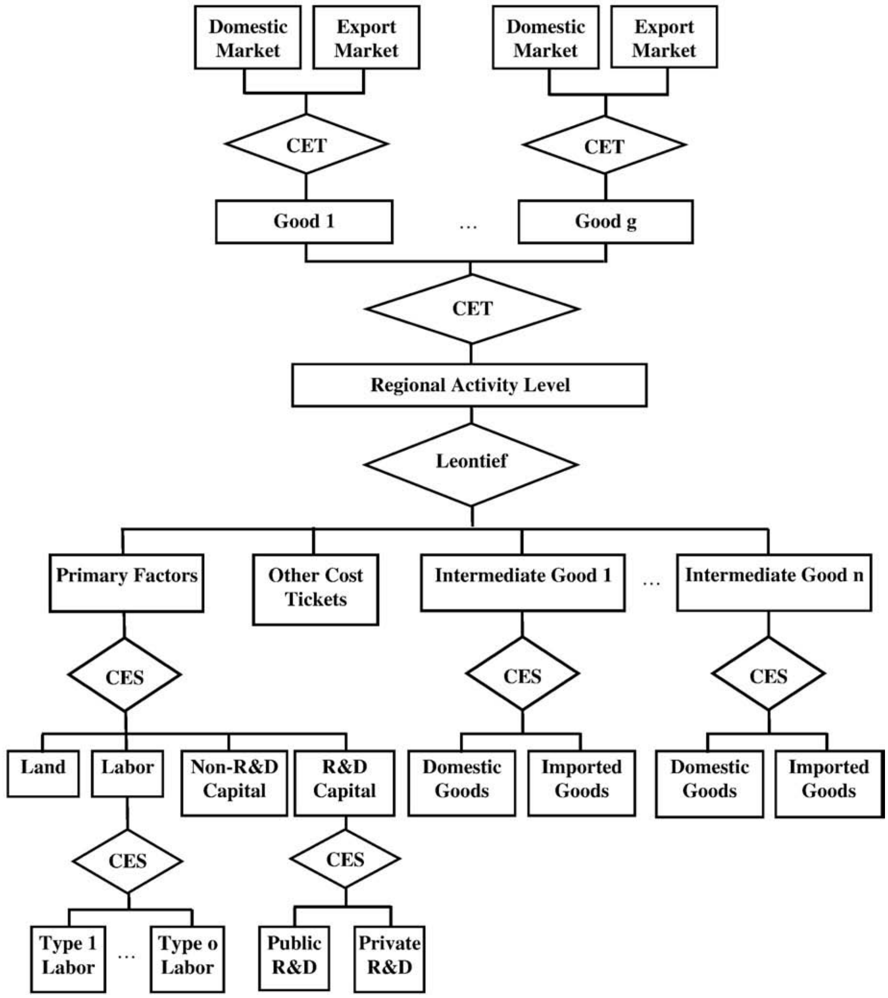

Fig. 1. The SciBud-CGE production structure.

further used to aggregate domestically produced and imported intermediate goods to obtain aggregate intermediate inputs.

The upper layer of the tree diagram assumes that there is no substitutive relationship between the aggregate primary input, other cost tickets[4] and aggregate intermediate inputs, and the Leontief production function is used to aggregate these inputs to obtain the final production volume of the industry concerned. The Leontief production function is expressed as follows:

$$\overline{Y} = C \times [B_1, \ldots, B_n] \tag{2}$$

where $\overline{Y}$ is the aggregate output of inputs, $B_1, \ldots, B_n$ are the aggregates of various inputs, and C is a parameter value.

The supply-side perspective of production depicts that the top layer of the tree diagram employs two constant elasticity of transformation (CET) functions to aggregate the products being supplied and can also derive the final production volume of the industry concerned. The CET function is expressed as follows:

$$Q = B\left[\sum_{i=1}^{g} \gamma_i Y_i^{-\rho}\right]^{-1/\rho} \tag{3}$$

where Q is the supply-side output, $Y_1, \ldots, Y_g$ are output levels of various products, and B, γ, and ρ are parameter values that satisfy $\sum_{i=1}^{g} \gamma_i = 1$.

In a traditional general equilibrium model, R&D and non-R&D capital inputs have the same effect on the production structure, but these two types of investment in fact have different induction multiples. Consequently, the SciBud-CGE model adopts an alternative approach to simulating the efficacy of R&D investment by using pre-estimated parameter differences to divide capital investment under an aggregate primary input into R&D and non-R&D capital inputs (see Fig. 1), to be followed by dividing the R&D capital input into public and private R&D capital inputs by using the CES function (see Section 3.3 for a detailed description of the functional mechanism).

3.1.2. Investment structure

As depicted in Fig. 2, the model assumes that the capital goods of various industries are constrained by the production function, and under such constraints industries will minimize their costs of forming fixed assets, of which capital goods have intermediate products locally produced or imported as their inputs, which are aggregated by the CES function (see the above section for the functional form). Finally, all capital goods are aggregated through the Leontief production function to obtain the aggregate capital goods of the industries concerned.

[4] Other cost tickets are miscellaneous production costs, the cost of holding liquidity, and the cost of holding inventory (Dixon et al., 1982).

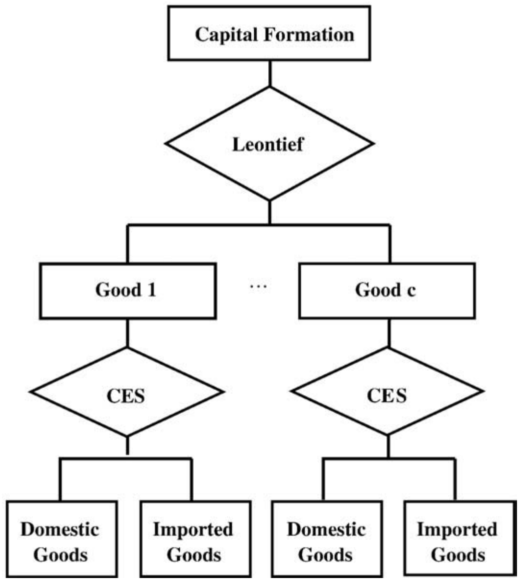

Fig. 2. SciBud-CGE capital formation.

3.1.3. Household consumption structure

The demand-side analysis focuses on household consumption utility as depicted in Fig. 3. The SciBud-CGE model adopts the Klein and Rubin (1947) utility function as the consumption function, which is expressed as follows:

$$U(Z_1,\ldots,Z_c) = \sum_{i=1}^{c} S_i^{\text{Lux}} \ln(Z_i - Z_i^{\text{Sub}}) \tag{4}$$

where Z_i is the total demand for product i; Z_i^{Sub} is the demand of consumers who consider product i to be a necessary good; $Z_i - Z_i^{\text{Sub}}$ is the demand of consumers who consider product i to be a luxury good, which varies with their incomes; and S_i^{Lux} is the share of the demand for luxury good i as the percentage of the total demand for luxury goods. The percentages of respective products possessed by households depend on the household income and the relative prices of products, which in turn affect the scale of the consumer's utility function.

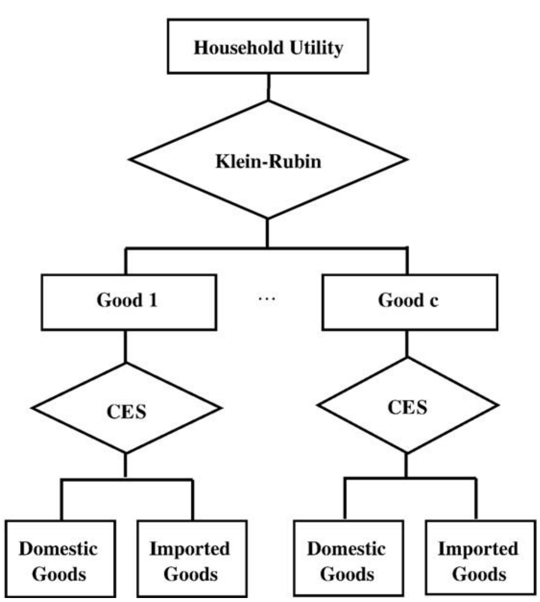

Fig. 3. SciBud-CGE consumer demand.

Household consumption for respective products in the region is aggregated into aggregate regional household consumption. All products being consumed are either produced domestically or imported from foreign regions, and the aggregation of these two types of products through the CES function results in the aggregate demand for all products.

3.1.4. Fiscal balance module

In order to reflect the fiscal balance under economic policy impacts or to simulate changes in fiscal revenues and fiscal expenditures due to the impacts on publicly funded R&D investment, the SciBud-CGE model incorporates a module of public finance that includes the definitions for the disposal of income, aggregate tax revenue, and savings in the private and public sectors, etc., as expressed in Eqs. (5)–(11). It is assumed in this study that there are no transfer payments in the economy. Hence the pre-tax GDP is equal to total output (Y) or total income.

$$\begin{aligned} GDP(\textit{Gross domestic product}) &= Y(\textit{Gross output}) = C(\textit{Consumption}) \\ &+ I(\textit{Investment}) + G(\textit{Government expenditure}) + X(\textit{Exports}) - M(\textit{Imports}) \end{aligned} \tag{5}$$

$$\begin{aligned} Y_d(\textit{Disposable income}) &= Y - T_i(\textit{Income tax}) \\ &= Y - T_L(\textit{Individual income tax}) - T_B(\textit{Business income tax}) \end{aligned} \tag{6}$$

$$T(\textit{Tax revenue}) = T_r(\textit{Indirect tax}) + T_i(\textit{Income tax}) \tag{7}$$

$$S_p(\textit{Private savings}) = Y(\textit{Gross output}) - T(\textit{Tax revenue}) - C(\textit{Consumption}) \tag{8}$$

$$S_g(\textit{Government savings}) = T(\textit{Tax revenue}) - G(\textit{Government expenditure}) \tag{9}$$

$$\begin{aligned} S(\text{Savings}) &= S_p(\text{Private savings}) + S_g(\text{Government savings}) \\ &= Y(\text{Gross output}) - C(\text{Consumption}) - G(\text{Government expenditure}) \end{aligned} \tag{10}$$

$$I(\text{Investment}) = S(\text{Savings}) - X(\text{Exports}) \tag{11}$$

The above equations are utilized in a sequential manner to construct within the SciBud-CGE a model that reflects the fiscal balance, and that includes individual income tax, business income tax, disposable income, private savings, public savings, tax revenue, and the fiscal deficit (see also Fig. 6). The SciBud-CGE model thus created is capable of simulating the effect of allocating new tax revenue or public expenditures for fiscal measures such as increasing public R&D investment. Consequently, the general equilibrium model used in this study is closer to the practices of public finance policies and generates more accurate outcomes of simulation analysis.

3.2. Dynamic mechanism of the SciBud-CGE model

SciBud-CGE is a model with a dynamic mechanism that mainly covers (1) the dynamic accumulation between investment and the capital stock, (2) positive correlations between investment and the expected rate of return, and (3) the relationship between the real wage rate change and employment (please refer to Dixon and Rimmer (2002) for the mathematical expression and an illustration).

The above operation of associating the three elements of capital accumulation, investment allocation, and the real wage rate adjustment represents the process of dynamic adjustment in the SciBud-CGE model. Once a dynamic model has been established, a recursive dynamic method is used to find the solution according to the following procedure. Take the base-year input–output data as the initial value and compute the impacts on the endogenous variables due to changes in the exogenous variables in year one. The equilibrium solution for year one is then used as the initial value for year two to find its solution, and then the same procedure repeats itself for the subsequent years. In such a way, the recursive dynamic method can be used to find a solution one year at a time, and the variables in each period and the next period are deemed to be sufficiently associated with each other.

3.3. Closure and calibration

Because in the process of finding solutions the number of endogenous variables in the model must be the same as the number of equations, a number of endogenous variables[5] must be assigned as exogenous variables. Consequently, a total of 25,099 equations are included in the dynamic SciBud-CGE model, and the closure criterion must be set for 7244 exogenous variables, as depicted in Table 1.

Before the policy simulation, the historical simulation must first be established and followed by the historical simulation calibration (2002–2008) and baseline forecast (2009–2019). The policy simulation is conducted to identify the difference before and after the policy's impact on the baseline forecast. The whole process is depicted in Fig. 4. First of all, two types of exogenous variables are designated for the historical simulation, one being the observable variable data and the other the historical data, which include land use volume, capital-augmenting technological progress, labor-augmenting technological progress, land-augmenting technological progress, shifters of the capital accumulation equation, shifters of the real wage rate, the consumption/capital ratio, inputs and outputs of industries, industrial investments, import goods, the labor employment levels of industries, the capital stock, aggregate consumer expenditure, the nominal wage, export goods, export prices, government expenditures, the return on capital for industries, the number of household units, import prices, tax rates, import tariffs, and exchange rates.

Furthermore, for the baseline forecasting closure, the endogenous and exogenous variables are swapped in such ways that the original endogenous variables are adjusted into exogenous variables and the original exogenous variables into endogenous ones that are determined internally by the model, so as to infer backwards the values of all variables in the historical simulation for the purpose of calibration. The policy simulation can then be performed after calibration. In addition, one basic way for the CGE Model to perform sensitivity analysis is repeated simulation (Harrsion and Kimbell, 1985) because the system model is usually big and non-linear. For simplicity and to save space, the present paper conducted a historical simulation to test for robustness and sensitivity by comparing the results with the real historical data (see Fig. 5). Other approaches involving numerical sensitivity analysis can be found in Pagan and Shannon (1985), Arndt and Hertel (1997), and DeVuyst and Preckel (1997).

By setting the closure criterion to perform the historical simulation and baseline forecasting on the real GDP growth rate, it has been found that historical simulation closely follows the route changes in the real data, as shown in Fig. 5. Furthermore, by referring to data from the report on long-term GDP forecasts published by Taiwan Power Company (Taipower, 2007),[6] the annual estimates are created to be used for baseline forecasting, so as to observe the impact generated by the policy concerned.

4. SciBud-CGE data structure

The SciBud-CGE model is created by selecting 16 industries (see Table 2) and 27 commodities required for the public R&D investment policy simulation in this study, while labor is further divided into 8 attributes: managers and supervisors, professionals, technicians and professional assistants, clerks, service personnel, sales, technical and machinery operators, non-technical labor, and physical labor. The basic data are compiled from the 2001 Input–Output Table, published by the Directorate-General of Budget, Accounting, and Statistics (DGBAS, 2003), Taiwan.

Table 1
SciBud-CGE closure.

Exogenous variables	Description
Real GDP supply-side	
x1lnd x1rad	Land and R&D capital
a1cap a1lab_o a1lnd	Technology changes
a1prim a1tot a2tot a1rad_s	Technology changes
faccum	Capital Shift variable
delfwage	Real wage rate shift variable
Real GDP expenditure side	
f3tot	Ratio of consumption/GDP
f5tot2	Ratio between shift of government expenditure/household consumption
invslack	Investment slack variable for exogenous investment
fx6	Capital stock shift variable
Foreign condition	
pf0cif	Import price
f4p f4q	Export price and demand shift variables
f4p_ntrad f4q_ntrad	Collective nontrade export price and demand shift variables
Investment	
finv2	Exogenous investment shift variable
finv4	Long run investment shift variable
Taxation	
delPTXRATE f3tax_cs f0tax_s	Changes in production tax and household tax rates, sales tax shifter
f5tax_cs t_lab t_busi t_rad	Changes in government usage tax, income taxes, and investment taxes
f4tax_ntrad f1oct f4tax_trad	Changes in nontrade export tax, other-costs tax, and trade export tax
f1tax_csi f2tax_csi t0imp	Changes in intermediate tax and investment tax, tariff
Others	
phi	Exchange rate
q	Household
emptrend	Long-term employment rate
delUnity	Dummy variable
rnorm	Nominal rate of return
gtrend	Long run ratio of investment/capital

Note: 7244 exogenous variables in total.

4.1. Input–output data

The input–output data are compiled based on the mutual relationships between the industrial structures, whereas the data are computed from the base value data.[7] Consequently, adequate data restructuring is required to roughly divide the database into output sectors, input sectors, and tariffs (see Fig. 6).

4.1.1. Input and output sectors

The output sectors are the sources of demand, which are categorized into 6 columns: intermediate demand, capital formation (investment), household consumption, exports, government consumption, and inventory changes. Intermediate demand and capital formation are further divided into intermediate industries while the others are all single sectors.

The input sectors are the cost structures of each output sector. There are 10 rows of costs: basic input, distribution margin, indirect tax, labor, individual income tax, capital, business income tax, land, production tax, and other cost tickets, of which the first three items are intermediate inputs while the remaining seven are primary factors needed for the output of all domestic producers. In this study, the individual income tax and business income tax are derived from labor

[5] In SciBud-CGE, the number of variables is larger than the number of equations.

[6] The Taiwan Power Company's long-term GDP forecast might not be the best reference data considering its 5-year forecast interval, but it offers a growth rate forecast for up to 15 years and can still be used as a baseline without affecting the policy simulation in this study.

[7] Base value data: data for which the margin and tax are not counted.

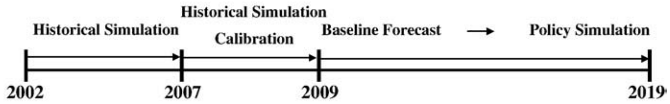

Fig. 4. SciBud-CGE closure and simulation.

payments and the capital return, respectively, to incorporate the fiscal data into the model.

Each type of product (C) can be divided into a domestic product or imported product. If we take the distribution sector as an example, in the basic input row, VIBAS stands for the domestic (or imported) product being provided to domestic producers as an intermediate input factor for the basic value matrix ($C\times S\times I$); V2BAS stands for the basic value matrix ($C\times S\times I$) for the capital formation sector of the final domestic (or imported) product being provided to all industries; V3BAS stands for the basic value matrix ($C\times S$) of the final domestic (or imported) product as consumption for the household sector; V4BAS stands for the basic value vector (C) of the final domestic (or imported) product for the export demand; V5BAS stands for the basic value matrix ($C\times S$) of the final domestic (or imported) product for the government sector; and V6BAS stands for the basic value matrix ($C\times S$) of inventory changes in the final domestic (or imported) product over the year.

The distribution margin is defined as expenses incurred from transshipping the product from its production location to its buyer and can be divided into domestic freight and overseas transportation. V1MAR stands for the freight (transportation) as well as commercial service matrix ($C\times S\times M\times I$) for transshipping the domestic (or imported) product as an intermediate input factor for all domestic industries; V2MAR stands for the freight (transportation) as well as commercial service matrix ($C\times S\times M\times I$) for transshipping the final domestic (or imported) product as capital formation for all industries; V3MAR stands for the freight (transportation) and commercial service matrix ($C\times S\times M$) for transshipping the domestic (or imported) product as final consumption for the household sector; V4MAR stands for the freight (transportation) and commercial service matrix ($C\times M$) for transshipping the final domestic (or imported) product for overseas demand; and V5MAR stands for the freight (transportation) and commercial service matrix ($C\times S\times M$) for transshipping the domestic (or imported) product as final consumption for the government sector. There are no data on the distribution margin for the inventory changes in the SciBud-CGE model since such changes can be positive or negative and can be adjusted based on the producer cost data.

The indirect tax comprises mainly two tax items, namely, the value-added tax and excise tax. The V1TAX row stands for the indirect tax matrix ($C\times S\times I$) for selling the domestic (or imported) product as intermediate input for all domestic producers; the V2TAX row stands for the indirect tax matrix ($C\times S\times I$) for selling the final domestic (or imported) product as capital formation for all industries; the V3TAX row stands for the indirect tax matrix ($C\times S$) for selling the final domestic (or imported) product for the household sector; the V4TAX row stands for the indirect tax vector (C) for selling the final domestic (or imported) product for export; and the V5TAX row stands for the indirect tax matrix ($C\times S$) for selling the final domestic (or imported) product for the government sector. There are no data on the indirect tax for the inventory changes in the SciBud-CGE model.

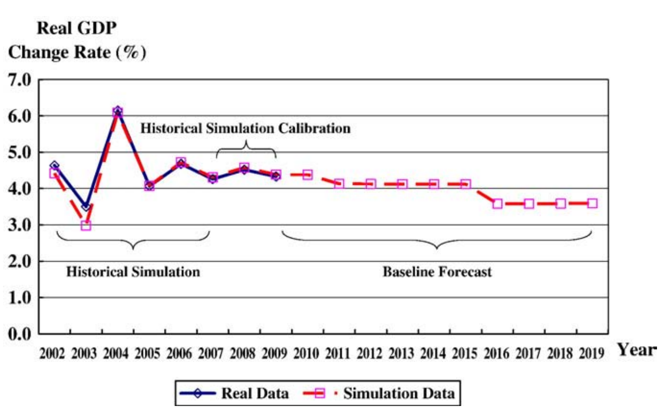

Fig. 5. SciBud-CGE simulation calibration and baseline forecast.

Table 2
Sample sizes of industrial panel data in 2001–2005.

Industries	2001	2002	2003	2004	2005
Agriculture	2273	2198	2348	2423	2498
Mining	872	876	868	864	860
Food, tobacco, and beverages	3528	3522	3534	3540	3546
Textile and leather	10,155	10,212	9881	10,474	9767
Wood, bamboo, paper, and printing	15,599	15,520	15,811	15,490	15,969
Petrochemical	11,865	11,474	12,256	12,647	13,038
Non-metallic	1919	1746	2092	2265	2438
Metallic	34,232	33,104	35,360	36,488	37,616
Machinery	17,164	17,258	17,070	16,976	16,882
Electric machinery	1173	1244	1102	1031	960
Information and computer	179	162	199	206	233
Electronic parts and components	6728	6634	6939	6683	7127
Other manufactures	7885	7952	7885	7618	7751
Water, electricity, and gas	246	260	232	218	204
Construction	72,245	69,863	74,627	77,009	79,391
Services	359,782	360,432	362,965	350,815	361,665
Subtotal	545,845	542,457	553,169	544,747	559,945

Note: There are in total 2,746,163 panel data entries for 16 industries.

4.1.2. Multi-production input sectors

The SciBud-CGE model allows each industry to produce multi-products in the same production process. Because the focus of this study was public R&D investments, in order to accommodate industries with higher weights in terms of R&D expenditures and invested manpower over the years, three indicative manufacturing industries – the petrochemical, information and computer, and electronic parts and components industries – were further subcategorized to identify those products with higher production values and significant world market shares for subsequent analyses in this study. In addition, the petrochemical sector was further divided into chemical materials, synthetic rubber, plastic products, and other petrochemicals; the information and computer sector was divided into computers, data storage products, optical products, motherboards, and other computer peripheral equipment; and the electronic parts and components sector was divided into semi-conductors, memory chips, integrated circuits, optoelectronics and liquid crystal panels, and other electronic products. The remaining industries had one product per industry.

4.1.3. Import tariff

The import tariff vector contains taxes charged on imported products and they are not user-based. Hence this vector itself stands for its tax revenue data.

4.2. Applications of GTAP database parameters

Parameters used in the SciBud-CGE model are basically obtained from the GTAP (2006) database. For matching the original industry categorization in the SciBud-CGE, the GTAP database has been aggregated into 16 industry categories. The data for the parameters for the Taiwan region used in the SciBud-CGE model are mainly drawn upon from the GTAP database together with data collected, inferred,

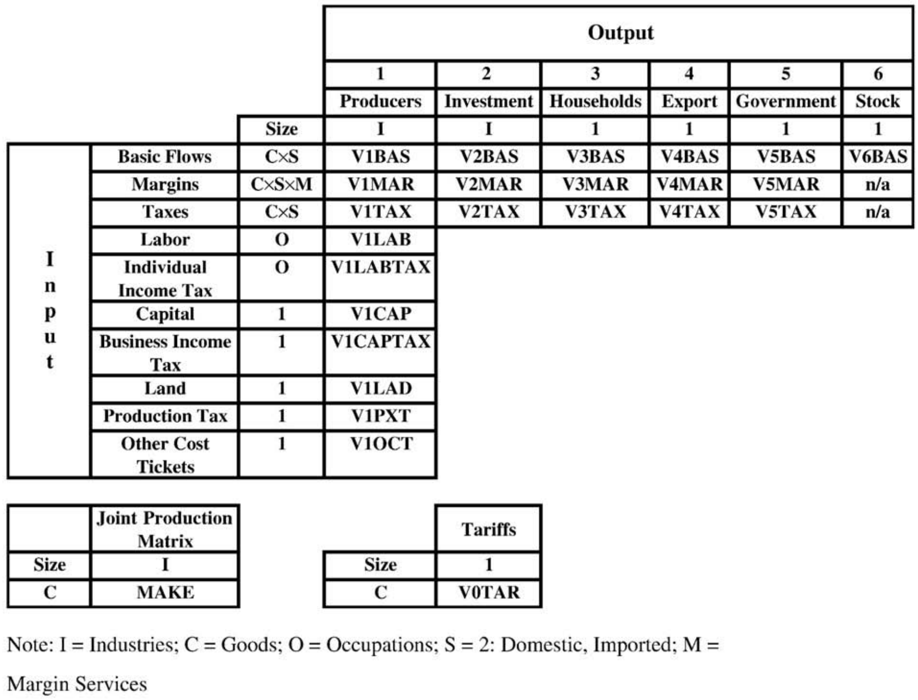

Fig. 6. SciBud-CGE data structure. Note: I = industries; C = goods; O = occupations; S = 2: domestic, imported; M = margin services.

or compiled from such parameters in the income tax and public R&D modules.

4.3. Public sector capital input

As depicted in the CGE production structure (Fig. 1), the input factors required for production activities included the three primary inputs of land, labor, and capital, all of which were integrated through the CES production function. Furthermore, since the effects of the R&D capital input and non-R&D capital input would have been different on the supply and demand sides, the capital input was divided into the two categories of R&D capital input and non-R&D capital input. In order to separate the R&D capital input from the non-R&D capital input, it was required that this study identify the percentages of returns on the capital input that were contributed by the R&D and non-R&D capital inputs, respectively. Also included in this study was the classification of R&D capital input into the public R&D input and private R&D input so as to analyze the shock effects of the public sector capital input.

First of all, the panel data (about 2.75 million entries, after eliminating unreasonable data, e.g., samples with excessive values, inconsistent totals or negative values; see Table 2) from the 2001–2005 annual tax database provided by the Ministry of Finance (MOF, 2005) in Taiwan were used to analyze the behavioral pattern of the capital inputs. This was followed by the decomposition of the linear model method to derive the percentage of the R&D capital input in the total capital input. The panel data model is designed as follows:

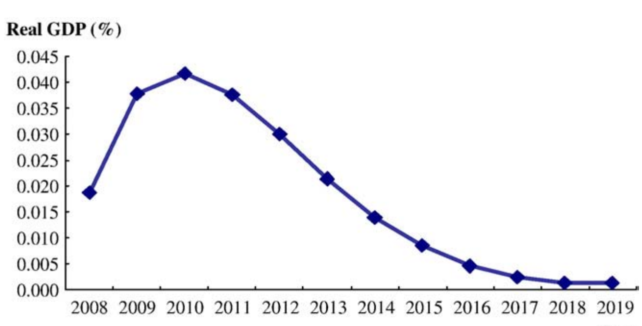

Fig. 7. Impact on real GDP.

$$y_{it} = \mu_i + \beta' x_{it} + \varepsilon_{it}, E(\varepsilon_{it}) = 0, (\varepsilon_{it}) = \sigma_\varepsilon^2 \quad (12)$$

where y is the gross profit of the producers, μ is the effect of industrial characteristics, and x consists of the contributing factors of gross profit, which include operating expenses, payroll, rent, and R&D expenditures (including those on research and training).

The above equation can be expressed as $y_{it} = \alpha_i + \beta' X_{it} + \varepsilon_{it}$ when applied to a constant effects model, or $y_{it} = \alpha + u_i + \beta' x_{it} + \varepsilon_{it}$, of which $E(u_i) = 0$, $\text{Var}(u_i) = \sigma_u^2$, and $\text{Cov}(\varepsilon_{it}, u_i) = 0$, when applied to a random effects model. For the estimation of the panel data model, the statistical test developed by Hausman and McFadden (1984) could be employed to determine whether a constant effects model or a random effects model is more appropriate: the higher the Hausman and McFadden statistics are, the stronger is the preference for a constant effects model. The test results in this study unanimously point to a constant effects model as being the more suitable choice.

Furthermore, the respective percentages for the R&D expenditures of the public and private sectors for the period 2001–2005 from the Indicators of Science and Technology, published annually by the National Science Council (NSC, 2005) in Taiwan, were selected to divide the R&D capital inputs derived from the constant effects model of panel data into yearly public and private R&D capital inputs by their respective percentages.

One of the major differences between this study and a traditional CGE model is that this study further included a detailed categorization of the capital input, which means that the capital input was divided into R&D and non-R&D capital inputs and then the R&D input was divided into public and private R&D capital inputs to investigate the respective shock effects of public R&D capital inputs from different sectors on the economy, thereby obtaining more comprehensive findings from the empirical analyses. Since a traditional CGE model does not have the subdivisions of capital inputs and therefore no relevant parameters were available in the GTAP (2006) database or other related references, in this study the categorized sample data were then used for estimation in the CES function, which is expressed as follows:

$$M_j = A\left[\sum_{i=1}^{2} \delta_{ij} R_{ij}^{-\rho}\right]^{-1/\rho} \tag{13}$$

where M_j is total R&D capital input in industry j; R_{1j} and R_{2j} are the respective public and private R&D capital inputs in industry j; and A, δ and ρ are parameters that satisfy $\sum_{i=1}^{2} \delta_i = 1$. This function was used for the non-linear model estimation with the SAS statistical program, from which the estimated parameters were adopted by the SciBud-CGE model for the shock simulation of the public R&D investment policy.

5. Empirical results of the SciBud-CGE model

In this age of technological competition, countries around the world have been joining in the race for R&D investment, cultivating talent, and developing priority technologies and industries due to a common belief in the positive economic benefits and competitive edge that can be created by the R&D capital input. As the effects of R&D investment on macro-economics have become a shared concern, the role of the government R&D input has been regarded as an important tool for economic development.

As described above, this paper basically adopted a dynamic CGE model to conduct empirical research that focused on the impact of public R&D capital inputs. Under the closure setting, a historical simulation and baseline predictions were performed first, and the results indicated that the historical simulation closely followed the historical data, as shown in Fig. 5. Furthermore, based on the long-term forecast made by Taiwan Power Company, the baseline predictions and policy simulation were conducted to observe the policy-induced shock (i.e., the difference between the baseline forecast and the policy simulation).

Based on real amount of the public R&D expenditures in the year 2008 (about 90 billion NT$, or about 0.73% of real GDP in Taiwan), this study analyzed changes in macro-economic variables as well as industrial outputs against the one-time shock of a 1% public R&D input increase. All impacts were found to deviate from the baseline forecasts.

5.1. Effects on macro-economic variables

In terms of the contribution to the economic growth rate (change in real GDP), as shown in Fig. 7, the impact was 0.017% in year 1, reached a peak of 0.04% in year 3, and then gradually declined and converged to the origin after 12 years. These findings indicate that the public R&D input could gradually induce domestic economic growth through the increase in R&D capital. Such results could not be achieved satisfactorily in a very short time (1 year) because R&D products require a certain period of time to mature in the market, which is about 3–4 years in Taiwan. After that, the dynamics in terms of economic growth diminish over time due to the loss of power with the continuing increase in R&D investment and the crowding-out effect among domestic industries.

From the analysis of the GDP expenditure side, economic growth was mainly attributed to exports, followed by government expenditure and household consumption. However, there existed a slight crowding-out effect in private investment. On the other hand, from the GDP income side, the increases in the R&D input were the main contributor to real GDP growth. The increases in R&D capital would have also led to the growth in labor employment in most R&D-intensive industries and, at the same time, would have crowded out labor employment in primary industries such as the agriculture and food, tobacco, and beverages industries (see the industrial change effects below).

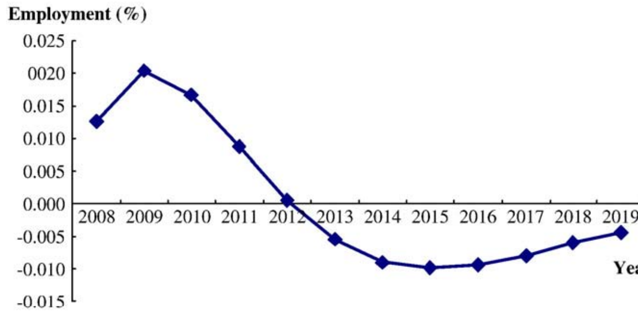

Fig. 8. Impact on employment.

In terms of changes in employment and the real wage, as shown in Figs. 8 and 9, in the short- and mid-term, due to the rise in the real wage rate and labor productivity, the employment had a positive effect (reached its peak at 0.02% in year 2). After the mid-term, from year 6 onward, a negative effect emerged because of the fall in the real wage and slow down in the spillover effect of the technology (or, labor productivity), and then gradually converged to zero in the long run. This indicated that, with the increase in the R&D capital input, the labor productivity rose significantly, too. Therefore, this created demand for labor in the short- and mid-term, with positive impacts being found in the first 5 years. In the long run, the shock effect gradually disappeared as the technology matured over time. This implication was consistent with the finding by Archibald and Pereria (2003) that, in the long-term, public R&D investment had no effect on employment, which is also reflected by the phenomenon of full employment in the long-term in economic growth theory (Abel et al., 2008). A closer look at individual industries revealed that the improvement in the employment level due to the R&D input was most effective in the electronic parts and components industry, followed by the information and computer products industry. On the other hand, the public R&D input did have a negative effect on primary industries such as agriculture and fishery. Such findings were also echoed by output changes for respective industries.

Due to the public R&D investment, the production cost of high-tech industries would have declined and enhanced international trade competiveness and subsequently increased export volume, as shown in Fig. 10. The peak was about 0.065% in year 4 and then gradually declined toward a new positive equilibrium. This implies again that R&D products reached a mature stage in 3–4 years in Taiwan. Because most of the domestic high-tech products were for the international

Fig. 9. Impact on real wage rate.

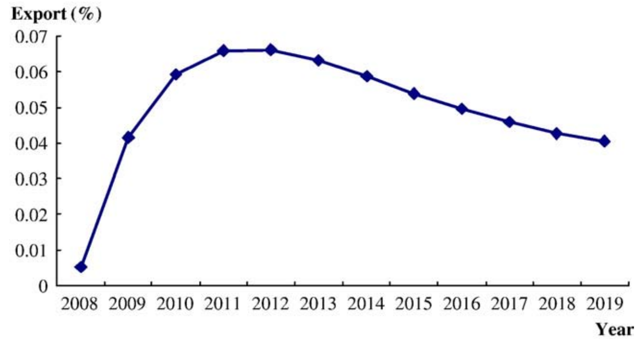

Fig. 10. Impact on exports.

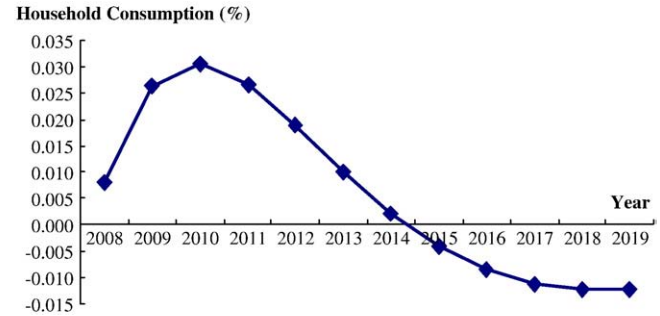

Fig. 13. Impact on household consumption.

market, public R&D investment provided a good foundation for exports in Taiwan; the more public R&D investment, the better the popularization of technology, and then the more exports.

In terms of price changes, as shown in Fig. 11, the public R&D input in the short-term led to an increase in total demand and the subsequent inflation of 0.045% in the first year. Later on, as total supply increased with technological advances, inflation was slowly reduced but still stood at 0.015% in the mid-term. In the long run, prices rose gradually and eventually converged to a positive steady equilibrium value (about 0.033%). It is noted that the impact pattern of the real wage rate moved in the opposite direction to the effect of a price change.

Regarding the effects on total tax revenue, as shown in Fig. 12, a peak of NT$350 million was present in the first period, indicating that tax revenue was subject to a maximal direct impact, before it gradually declined to a steady positive equilibrium value. Consequently, increasing government R&D investment seems to be a good policy from a public finance perspective because the tax revenue was not completely diluted at all since the tax base became larger and increasingly positive.

In terms of household consumption, as shown in Fig. 13, the effect increased in the short- and mid-term, from 0.008% in year 1 to 0.03% in year 3, and then gradually declined to a negative equilibrium value. This result was confirmed from the changes in employment, the real wage, and the price level. In the short- and mid-term, the increase in employment coupled with the growth in the real wage rate gave rise to a positive change in household consumption. In the long-term, a decline in employment and gradually rising inflation caused consumption patterns to move in the opposite direction. This implied that follow-up policies for public R&D expansion might be required to redress the decline in consumption in the long run.

5.2. Impacts on specific industries

Basically, the volumes of the R&D input and in-depth technology vary with industries, from which it can be inferred that the public R&D investment policy effect also varies with industries. For simplicity, this

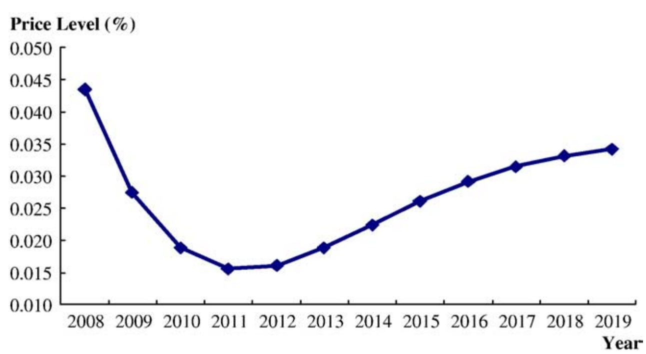

Fig. 11. Impact on price change.

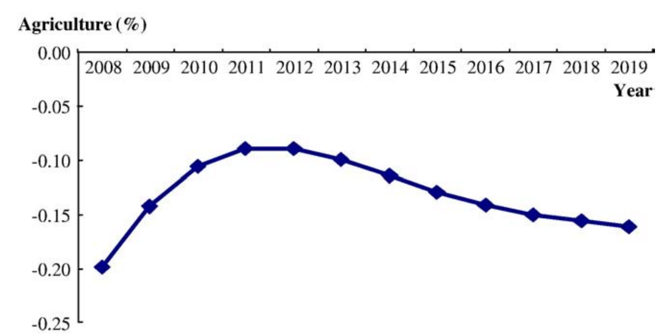

Fig. 14. Impact on agriculture industry.

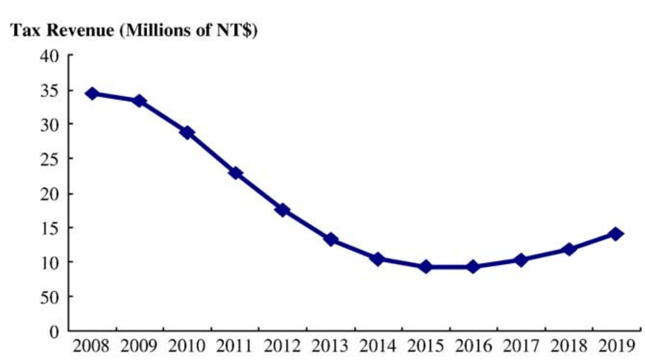

Fig. 12. Impact on tax revenue.

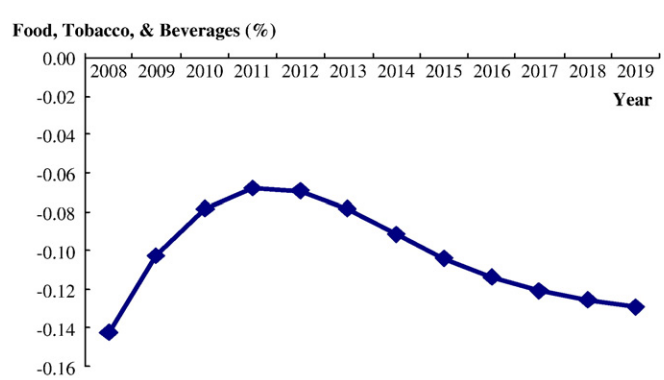

Fig. 15. Impact on food, tobacco, and beverages industry.

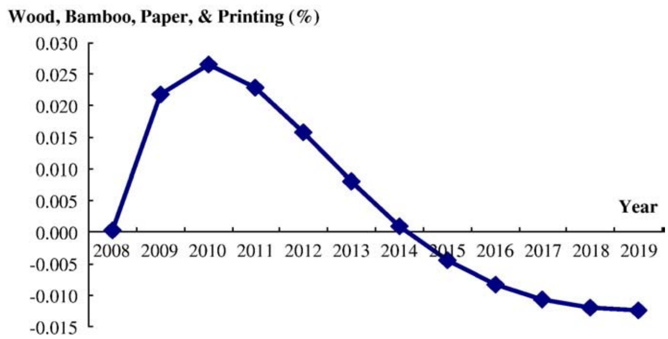

Fig. 16. Impact on wood, bamboo, paper, and printing industry.

section investigates the impact of the most important changes on different industries to serve as a policy-making reference.

First of all, from Figs. 14 and 15, the agriculture and food, tobacco, and beverages industries experienced the strongest crowding-out effects among all industries, or about −0.2% and −0.14%, respectively, in the first year. This negative impact was gradually relieved later on but the crowding-out effect still existed in the long-term. This implies that capital, labor, and resources would lead to a decline and decay in primary industries, which represents an issue that deserves the government's attention.

As for the impact on traditional industries, such as the wood, bamboo, paper, and printing (Fig. 16), non-metallic (Fig. 17), metallic (Fig. 18) and construction (Fig. 19) industries, two distinct stages of output change were identified. First of all, the effect was initially positive until it reached a certain level, at which point it began to decline toward a negative equilibrium value. It can be inferred from this phenomenon that the public R&D input in the short-term could generate growth in traditional industries, but in the mid- and long-term it would result in a decline in output due to changes in the industrial structure and the loss of labor force. As for the public utility sector, although it is also a traditional industry, positive effects were found not only in the short- and mid-term but also in the long-term (Fig. 20). This is because most of the public utility companies are owned by the government, and this industry experienced little in terms of a crowding-out effect as a result of the public R&D shock. However, the pattern of the downward U shape was similar to that in other traditional industries.

As regards the high-tech industries, such as the petrochemical (Fig. 21), electrical machinery (Fig. 22), information and computer (Fig. 23), and electronic parts and components (Fig. 24) industries, all of these experienced positive effects. The strongest effects were felt in year 2 to year 5, after which there was a shift toward a steady equilibrium value. Positive effects dominated all periods. This phenomenon of high-tech industry development satisfied not only

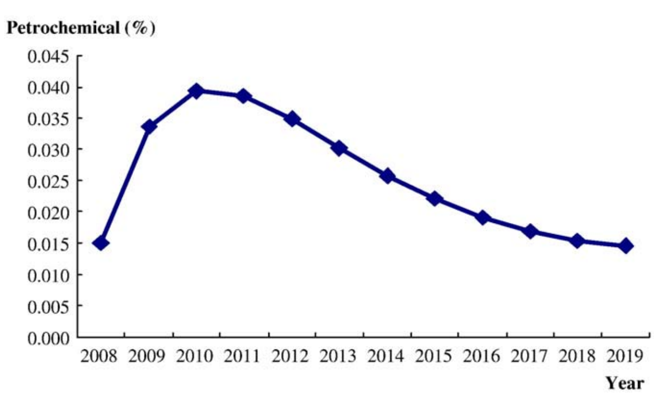

Fig. 17. Impact on non-metallic industry.

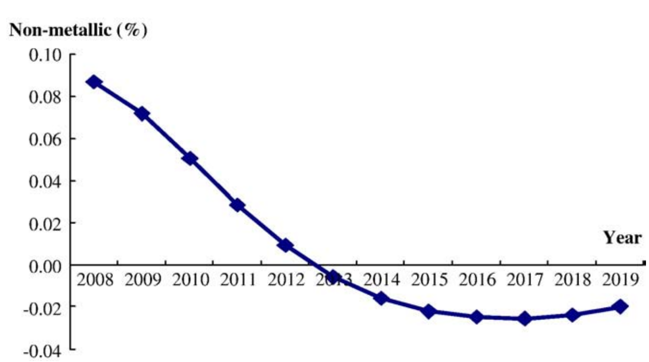

Fig. 18. Impact on metallic industry.

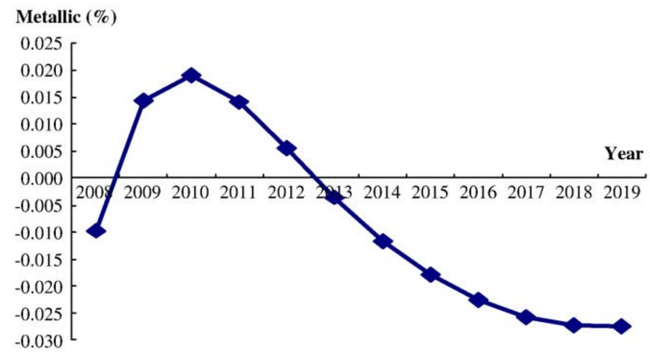

Fig. 19. Impact on construction industry.

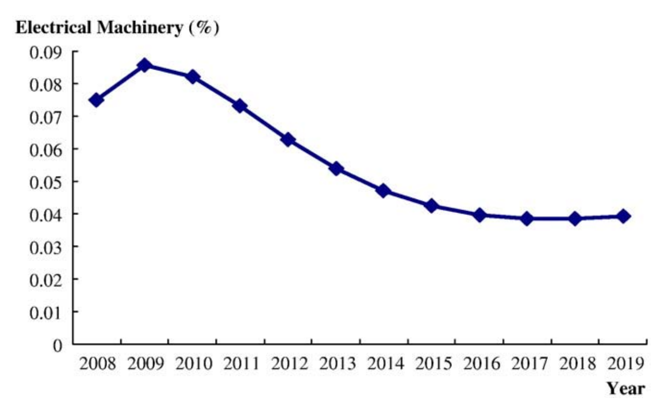

Fig. 20. Impact on water, electricity, and gas industry.

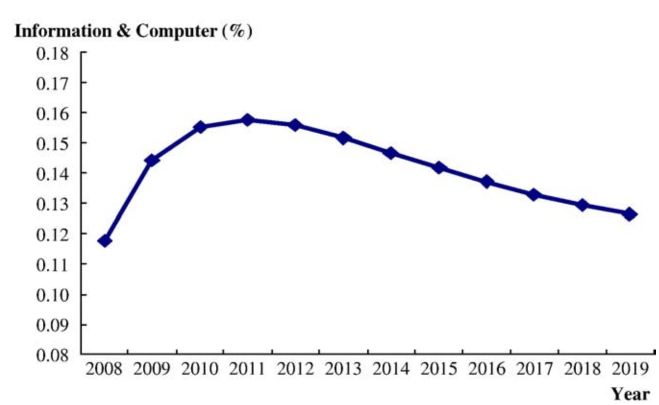

Fig. 21. Impact on petrochemical industry.

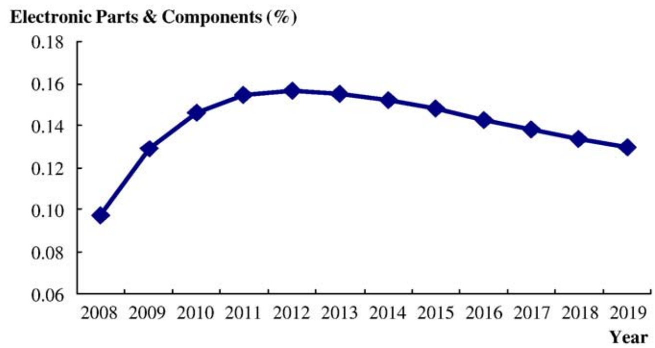

Fig. 22. Impact on electrical machinery industry.

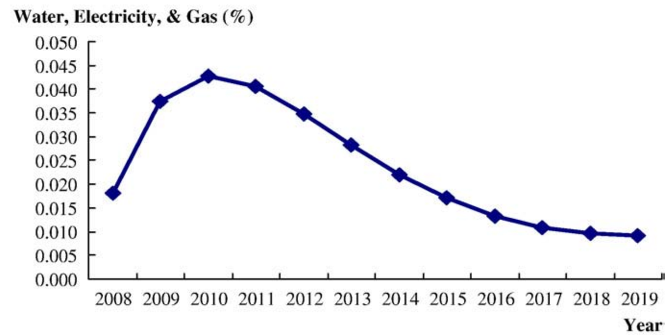

Fig. 24. Impact on electronic parts and components industry.

the goal of government officials but also the economic development theory.

To sum up, the empirical evidence of this paper has pointed out that the public R&D input did improve economic growth in the short- and mid-term. The greatest benefits were achieved when R&D products or technologies reached their mature stage, after about 3–4 years in this study. All the macro-economic variables gradually converged to new equilibrium statuses if there was no continuing impact from the R&D shock. However, the government still needs to attend to issues such as inflation and the decline of primary industries as a result of R&D investment by means of necessary adjustments to macro-economic policies and supplementary subsidy measures, so as to avoid unnecessary political conflicts.

6. Conclusions and remarks

This study aims to incorporate an input–output table, public finance theory, dynamic mechanisms, and an R&D module into a new dynamic SciBud-CGE model so as to perform a shock simulation on government R&D investment — a problem that is of much concern to the government administrators as well as researchers in Taiwan.

The research findings based on this SciBud-CGE model indicate that the public R&D input had a positive effect on real GDP in the short-term (about 0.02%) and the mid-term (about 0.04%), and, in the long-term, it led to growth in export volume and in the high-tech industries as well as to a steady increase in the real wage. The life cycle for a mature stage of R&D products (technologies) is about 3–4 years in Taiwan. These findings imply that R&D investment would enable technological advances to sustain long-term economic growth through continuous improvements in human capital or labor productivity. However, caution is needed with regard to the labor force issue of a rising unemployment rate in the mid and long-term that is caused by advances in technology, and the government is therefore advised to respond to such changes in the industrial structure by enhancing vocational and technical training to upgrade labor force quality. From a historical perspective, economic growth leads to price increases, and due attention must therefore be given to monitoring whether or not the price rise induced by public R&D investment is still within the reasonable expectations of society. In order to avoid any undesirable price volatility, supply-side policies with R&D innovation may be adopted to increase business productivity and gradually offset the inflation effect.

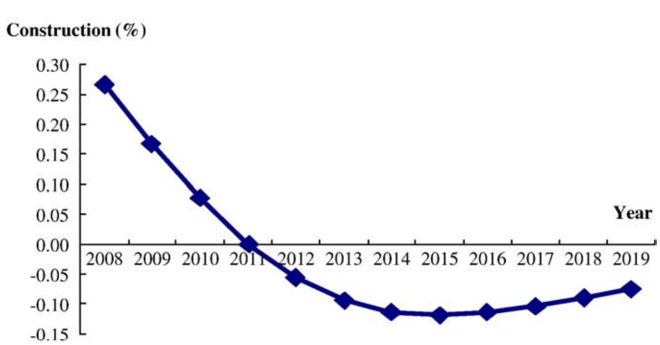

Fig. 23. Impact on information and computer industry.

In industry-specific analyses, primary industries such as the agriculture and food, tobacco, and beverages industries must be guided toward transformation into more sophisticated industries to avoid the crowding-out effect brought about by investment in public R&D in science and technology. Traditional industries that have relatively low R&D inputs may experience short-term growth, but in the long-term they still have to deal with negative effects induced by changes in the industrial structure. Hence, technological innovation engaged in by the R&D department has become an imperative issue for the traditional industries to effectively respond to the challenges of technological advances.

This study has addressed difficulties encountered by a traditional CGE model in regard to the R&D investment aspect by installing a new R&D investment module to evaluate the economic impact of public R&D investment. In the past, theoretically sound evidence of the estimated economic benefits has been missing in the government's efforts to advocate policies for public R&D input, which often included only certain quantified indicators such as the numbers of patents and papers, and have failed to elaborate on the specific questions of real GDP growth, employment, inflation, and industrial change. This study offers a new empirical CGE model that elaborates on the positive and negative impacts of public R&D investment. On the whole, the economic benefits of the public R&D input have outweighed its drawbacks and resulted in economic growth. The empirical evidence presented in this paper may serve as a valuable source of reference both with academic significance and with relevance to policy.

For future studies, the model's structure could be further enhanced by incorporating the relationship between the labor and capital inputs to construct an endogenous growth model. Subsequent studies may include developing specific modules such as the human capital model and the open competition model to further investigate the mobility and competition in the primary factor market. Because the CGE model is huge and complex, many of its modules must be separately processed for estimation before the simulation of the overall system is performed, which is a task that, while highly time-consuming, will surely prove to be worth the effort.

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