Energy Substitution in CGE Modeling
Using the "Technology Bundle" Approach: The Case of Taiwan

by

Ping-Cheng Li, Chung-Huang Huang, and Shih-Hsun Hsu*

Abstract

In this article, we adopted the technology bundle approach proposed in ORANI-E, MEGABARE, and GTEM. The analysis of GHG emission abatement scenarios is based on simulation results from TAIGEM (TAIwan General Equilibrium Model), a dynamic, multisectoral, applied general equilibrium model of the Taiwan's economy, developed specifically to analyze climate change response issues. Results clearly demonstrate that absence of the technology bundle approach in modeling electricity industry leads to overestimation of CO2 baseline projection and, hence, larger carbon tax at the higher expense of GDP loss. Moreover, TAIGEM©-D restricts substitution to known technologies, thereby preventing technically infeasible combinations of inputs being chosen as model solution.

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1. Introduction

Recently, the distinction between a “top down” (e.g., TAIGEM©-D model) and “bottom up” (e.g., TAIWAN-MARKAL model) approach to modelling the energy sector has received a great deal of attention in the discussions of projected emissions growth in Taiwan. One of the major conclusions of the 1998 National Energy Conference is to improve Taiwan’s CO_2 baseline forecasting using both top-down and bottom-up approaches. Progress in taking technology bundle approach (MARKAL-like structure) into a TAIGEM©-D CGE framework has been made. The major objective of this paper is to bring into focus energy substitution in CGE modelling using the technology bundle approach with a case study of Taiwan.

Attempt to absorb a detailed energy model such as MARKAL into a CGE framework was pioneered by Manne (1991). Continuous progress towards this line of analysis has been made by Adams et al. (1991), Jones et al. (1991), McDougall (1993a, 1993b), and ABARE (1996). It is usually conceded that the 'top down' models are superior in capturing extensive interactions with the other sectors of the economy but the 'bottom up' models achieve much greater realism in modelling the substitution options in energy production technology.

In this paper, the analysis of GHG emission baseline and carbon taxes policy simulations with and without the technology bundle approach is based on forecasting results from TAIGEM©-D (TAIwan General Equilibrium Model-Dynamic). TAIGEM©-D is a dynamic, multisectoral, computable general equilibrium (CGE) model of the Taiwan’s economy. We use historical simulations to generate up-to-date data for our baseline forecasting.

TAIGEM©-D is descended from the TAIGEM© model, developed specifically to analyze climate change issues, such as baseline forecasting, climate change response policies. TAIGEM© is a multisectoral, computable general equilibrium model of the Taiwan’s economy derived from ORANI (Dixon, Parmenter, Sutton and Vincent, 1982). The input-output database was compiled from the 150-sector Use Table of the 1994 Taiwan’s Input-Output tables. TAIGEM© distinguishes 160 sectors, 6 types of labor, 8 types of margins and 170 commodities. Like ORANI, TAIGEM© was designed for comparative-statics, i.e., for projecting what difference a shock would make to the economy at a point in time. The most significant features that distinguish TAIGEM©-D from TAIGEM©are the inclusion of interfuel substitution, technology bundles and dynamic mechanism capable of projecting the development of the economy through time. With TAIGEM©-D we have made annual projections of CO_2 emission, GDP growth rate, and other economic variables.

The next section demonstrates the idea and the advantages of the technology bundle approach. Section 3 provides an overview of other energy substitution features in TAIGEM©. Section 4 focuses on the major assumptions and baseline forecasting results of TAIGEM©-D model. Baseline projection and carbon tax simulation results with and without the technology bundle are compared. The last section provides concluding comments.

2. The Technology Bundle Approach

The way in which the technology bundle approach ensures that the pattern of input use is consistent with known technologies is illustrated in Figure 1. Figure 1 is a vector diagram corresponding to three techniques (X_1, X_2, and X_3), each involving different ratios of per unit of electricity generated requirements for labor and capital. The input combination used by the more capital intensive technology to produce a given level of electricity is shown by the point T_1. The input combination used by the more labor intensive technology to produce the same level of electricity is shown by the point T_3. Intermediate combinations lie on the two linear segments to the isoquant.

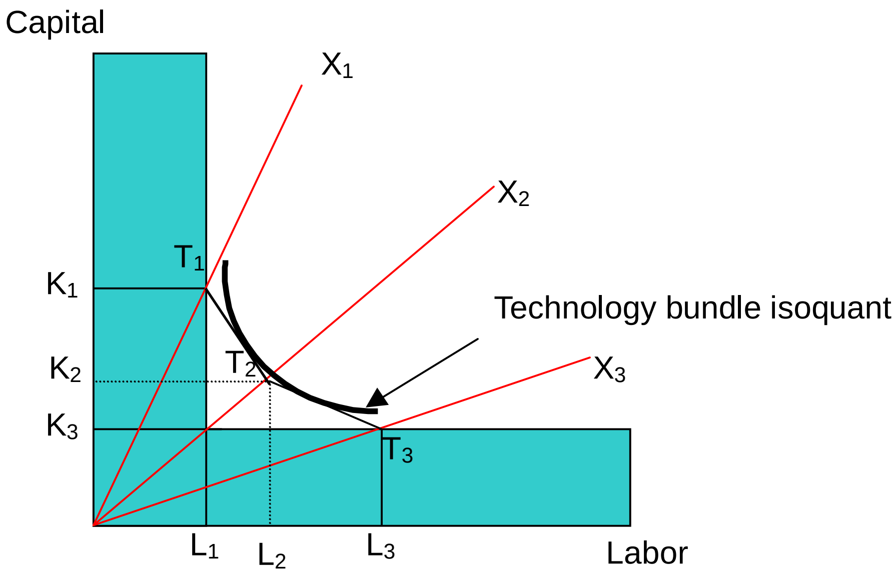

Figure 1. Isoquant for technology bundle

The kink line $T_1T_2T_3$ corresponds to a given output of electricity generated. In this case there are two linear segments to the technology bundle isoquant, each with its own marginal rate of substitution of capital for labor. Taken together, these two segments provide a piecewise linear approximation to the technology bundle (curved) isoquant, and it is not difficult to see that by adding more activities to the model, any desired degree of precision could be attained in approximating a given set of technology bundle (curved) isoquants.

When activities for different techniques are included in a linear programming model in this way, at most two of the activities will be included in an optimal solution. Further, if two activities are selected, they must always be adjacent activities when ranked by their relevant factor ratios. However, incorporating factor substitution possibilities into linear programming models usually renders the model much more flexible when solving for different prices or factor supplies.

In Figure 1 is shown the technology bundle isoquant used in CGE models. The technology bundle isoquant produces at least three advantages. First, it is evident that each of the two linear segments represents the isoquant that would be derived if the alternative technologies were perfect substitutes. If the alternative technologies were imperfect substitutes, the technology bundle isoquant would be convex with respect to the origin and lie above the perfect substitution isoquant.

Second, the points T_1 and T_3 in Figure 1 establish two critical regions shown by the shaded areas. Points in both the shaded area below T_3 and the shaded area to the left of T_1 imply input combinations inconsistent with known technologies. In contrast, the typical form of isoquant in standard microeconomics textbooks is asymptotic to both axes, it crosses into regions of technologically infeasible input combinations.

Third, the technology bundle isoquant may be viewed as an approximation to the piecewise linear technologies. The more technologies the model has, the lower the technology bundle isoquant. That is, the technology bundle isoquant is closer to the origin (and less costly) than the typical form of isoquant in standard microeconomics textbooks.

In TAIGEM©-D, production in the electricity sector is modeled using the "technology bundle" approach derived from Australia ORANI-E model and MEGABARE (GTEM) model. With this approach, electricity can be generated from coal, petroleum, gas, nuclear, hydo or renewable based technologies. The electricity industry is able to substitute between technologies in response to changes in their relative costs. By modeling energy intensive industries in this way, TAIGEM©-D restrict substitution to known technologies, thereby preventing technically infeasible combinations of inputs being chosen as model solutions. While retaining the extensive interaction with other sectors of the economy obtained in "top down" models, TAIGEM©-D moves further toward the realism of the "bottom up" approach.

In TAIGEM©-D model, 10 known technologies are used to generate electricity, namely hydro, stream turbine-oil, stream turbine-coal, stream turbine-gas, combined cycle-oil, combined cycle-gas, gas turbine-oil, gas turbine-gas, diesel, and nuclear. As shown in Figure 2, all electricity generated from these technologies is transferred to the end-use electricity sector. The output of the electricity sector is a CRESH aggregate of each electricity technology, and this technology requires fixed proportions of intermediate inputs, with the exception of energy inputs and primary factors.

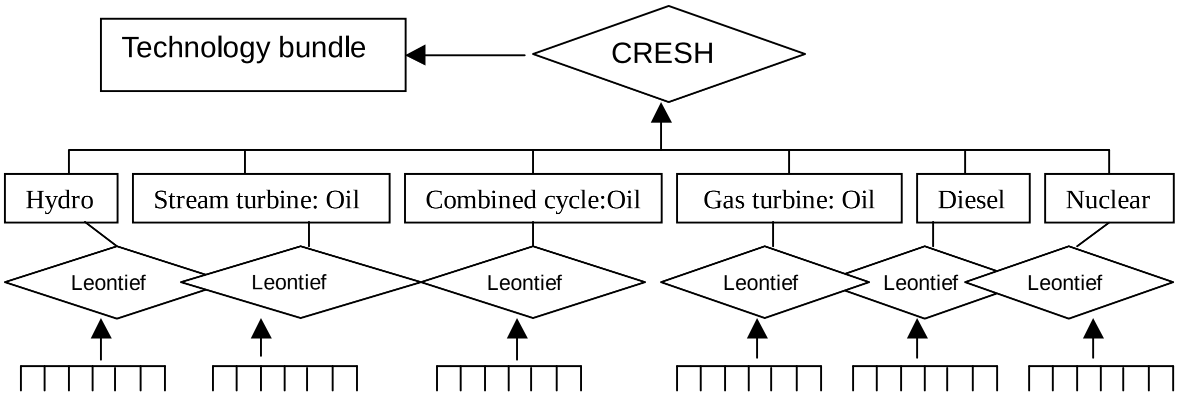

Figure 2. Technology Bundle of TAIGEM©-D Model: Electricity Sector

3. Other Energy Substitution Features in TAIGEM©

For each of non-electricity sectors, TAIGEM© allows each industry to produce several commodities, using as inputs domestic and imported commodities, labor of several types, land, capital, energy of several types and "other costs". In addition, commodities destined for export are distinguished from those for local use. The multi-input, multi-output production specification is kept manageable by a series of separability assumptions, illustrated by the nesting shown in Figure 3 which shows the production structure of the non- electricity sectors of TAIGEM© model.

The input demand of industry production is formulated by a five-level nested structure, and the production decision-making of each level is independent. Assuming cost minimization and technology constraint at each level of production, producers will make optimal input demand decisions. At the top level, commodity composites and a primary-factor composite are combined using a Leontief production function. Consequently, they are all demanded in direct proportion to the industry activity. At the second level, each commodity composite is a CES (constant elasticity of substitution) function of domestic goods and the imported equivalent (the Armington assumption). Energy and primary-factor composites are a CES aggregation of energy composites and primary-factor composites.

At the third level, the primary-factor composite is a CES aggregation of labor, land, and capital, and the energy composite is a CES aggregation of coal products composites, oil products composites, natural gas products composites, and electricity. At the fourth level, the labor composite is a CES aggregation of managers, professional specialists, white collar, technical, workers, and unskilled workers; the coal products composite is a CES aggregation of coal and coal products; the oil products composite is a CES aggregation of gasoline, diesel oil, fuel oil, and kerosene; the natural gas products composite is a CES aggregation of refinery gas, gas, and natural gas. At the bottom level the energy composite is a CES aggregation of domestic goods and imported goods.

Like ORANI model, the output structure of TAIGEM©-D allows for each industry to produce a mixture of all the commodities. Moreover, conversion of an undifferentiated commodity into goods destined for export and local use is governed by a CET (constant elasticity of transformation) transformation frontier.

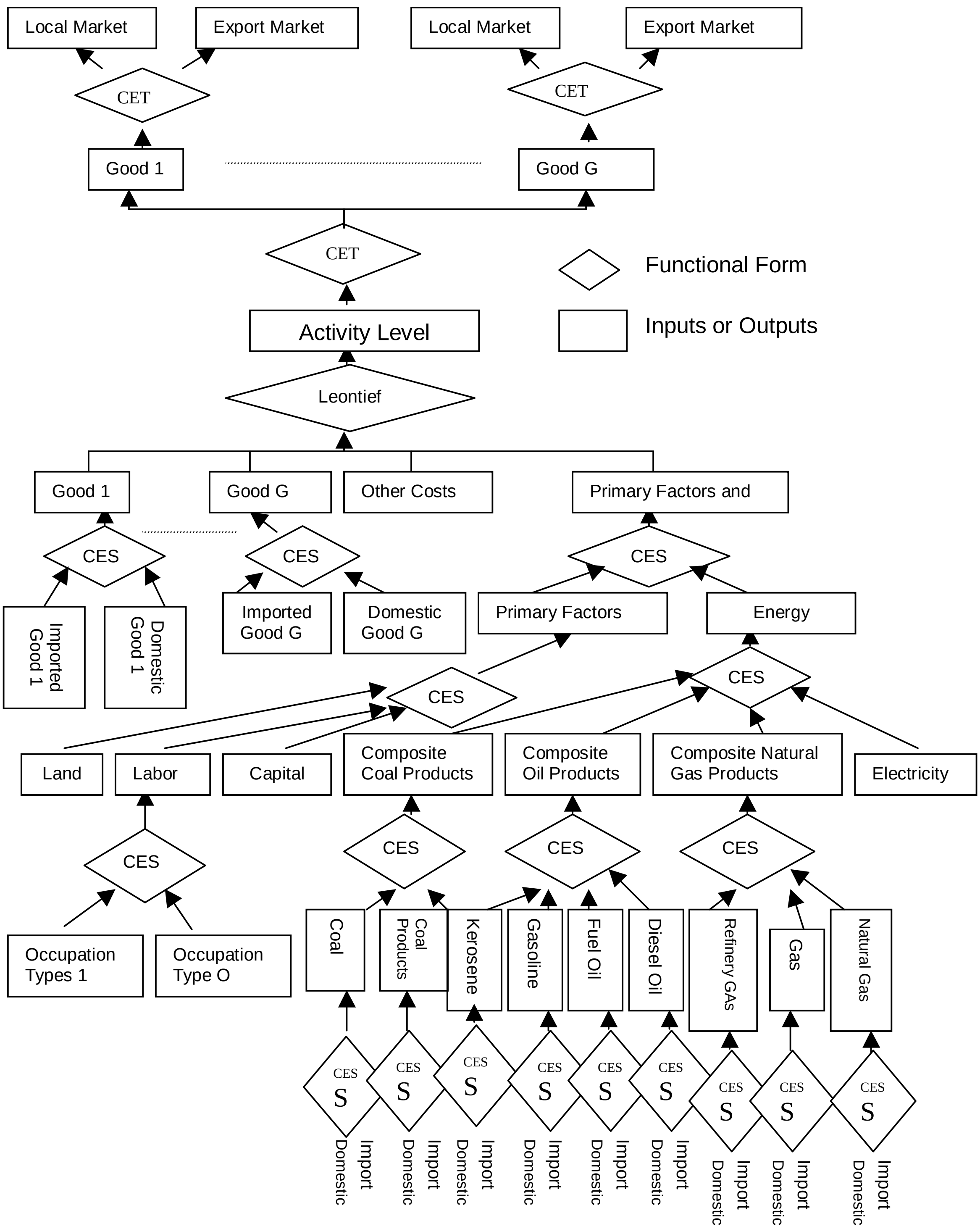

Figure 3. Structure of Production: Non-Electricity Sectors

4. Carbon Tax Simulation Results with and without the Technology Bundle

According to the conclusion of 1998 National Energy Conference, Taiwan proposes to reduce her greenhouse gas emissions to about 10% below or above her 2000 level for the commitment year, 2020. However, there were lots of debates on the baseline projection generated from the Taiwan Markal model. In this section we will examine baseline projections produced from TAIGEM©-D model with and without the technology bundle specification. For policy simulation we implement the carbon tax at year 2011 as an example and analyze different simulation results with and without the technology bundle specification.

For the CO_2 baseline forecasting, we consider the period from 1995 to 2020 as shown in Table 1 and Figure 4. The initial database of TAIGEM©-D model is the 1994 input-output tables. Real GDP growth rates are set endogenous. Three situations are specified as follows.

1) Historical closure in the period 1995-1997: Since official data on private consumption, investment, government consumption, exports, exchange rate and labor employed are available from the Directorate-General of Budget, Accounting Statistics, (DGBAS), we set growth rates of these variables as exogenous.

2) Closure for the year 1998: There are three differences between the closure for year 1998 and the historical closure for the period 1995-1997. Firstly, total labor employed is set exogenous in the historical simulation for the period 1995-1997. However, since official data on total labor employed at year 1998 is not available, we set it as endogenous. Secondly, aggregate price index is set as numeraire in the historical closure for the period 1995-1997, but consumer price index is set as numeraire in the closure for the year 1998. Thirdly, exchange rate is set exogenous in the historical closure for the period 1995-1997, but there is a closure swap between exchange rate and productivity growth rate of primary factors in the closure for the year 1998.

   Our aim with TAIGEM©-D was to use all the information for the final year (i.e., year 1998) which was available from the DGBAS, both in published and unpublished form. The results also provide quite detailed estimates of changes in technology over the historical period. We use these as the starting point for devising forecasting simulation on technical change to be incorporated into our baseline forecasts with TAIGEM©-D.

3) Forecast closure in the period 1999-2020: Most exogenous variables in the historical closure for the period 1995-1997 are set endogenous in the forecast closure. In the baseline forecast, private consumption, investment, government consumption, exports

and imports are determined in the model.

As shown in Table 1, baseline forecasting result shows that CO_2 emission is at 467 million tons with technology bundle and at 476 million tons without technology bundle at year 2020. It clearly demonstrates that the technology bundle approach incorporates feasible technology substitution possibilities into the model and renders the model much more flexible when solving for different prices or factor supplies. Therefore, its CO_2 emission levels are generally lower than those without the technology bundle approach (Figure 4).

In order to reach the year 2000 emission target set by the 1998 National Energy Conference, we adopt two policy measures. Namely, raising energy usage efficiency from 0.3% (baseline) to 5.3% and implementing the carbon tax at year 2011. As shown in Table 1 and Figure 5, with the technology bundle the US$41.4 per ton of carbon is solved to bring CO_2 emission level at year 2020 (231 million tons) back very close to its year 2000 emission target (230 million tons). However, without the technology bundle the US$41.4 per ton of carbon is not enough to get the target. That is, carbon tax should be raised to US$55.8 per ton of carbon at a cost of lower GDP growth rates (Figure 6). It is apparent that the technology bundle isoquant is closer to the origin (and less costly) than the typical form of isoquant without the technology bundle.

Table 2 shows the energy structure projection. With the technology bundle both in baseline and carbon tax simulation, the energy structure tends to use more amount of electricity generated from hydro and nuclear power. For example, during year 2016-2020 nuclear power share is raised from 10.68% to 11.50% for baseline and from 15.36% to 17.83% for carbon tax simulation. Hydro power share is raised from 3.12% to 4.30% for baseline and from 4.48% to 6.64% for carbon tax simulation. Natural gas usage has a similar pattern. Its share is raised from 7.02% to 7.14% for carbon tax simulation.

Table 3 presents some important energy indexes for different scenarios. Energy elasticity is % change in energy use over % change in GDP. Baseline results show that average energy elasticity is around 1.0 that is close to that in developed countries. CO_2 elasticity is % change in CO_2 emission over % change in GDP. Energy intensity is KLOE over real GDP. CO_2 intensity (ton per million NT dollars) is CO_2 emission over real GDP. With the technology bundle the CO_2 intensity is lower in baseline projection (22.43 versus 25.07) and in carbon tax simulation (14.47 versus 15.14).

Table 1. CO_2 Emissions with different scenarios

Year	CO2 Emissions (Million tons)									
	energy usage efficiency = 0.3%				energy usage efficiency = 5.3%					
	baseline				carbon Tax					
	tech bundle		non-tech bundle		tech Bundle		non-tech bundle			
					US$41.4 / ton carbon		US$41.4 / ton		US$55.8 / ton	
	GDP%	CO2	GDP%	CO2	GDP%	CO2	GDP%	CO2	GDP%	CO2
1994		167.14		167.14		167.14		167.14		167.14
1995	6.03	175.178	6.03	175.305	6.03	175.178	6.03	175.305	6.03	175.305
1996	5.67	182.962	5.67	183.349	5.67	182.962	5.67	183.349	5.67	183.349
1997	6.77	196.246	6.77	197.256	6.77	196.246	6.77	197.256	6.77	197.256
1998	4.83	203.716	4.83	205.006	4.83	203.716	4.83	205.006	4.83	205.006
1999	5.59	218.447	5.59	220.022	5.59	218.447	5.59	220.022	5.59	220.022
2000	5.77	230.355	5.78	232.541	5.77	230.355	5.78	232.541	5.78	232.541
2001	4.85	240.827	4.87	243.508	4.85	240.827	4.87	243.508	4.87	243.508
2002	4.25	250.65	4.28	253.735	4.25	250.65	4.28	253.735	4.28	253.735
2003	3.87	260.388	3.90	263.698	3.87	260.388	3.90	263.698	3.90	263.698
2004	3.64	270.242	3.64	273.547	3.64	270.242	3.64	273.547	3.64	273.547
2005	3.50	280.191	3.49	283.427	3.50	280.191	3.49	283.427	3.49	283.427
2006	3.41	290.181	3.41	293.444	3.41	290.181	3.41	293.444	3.41	293.444
2007	3.37	300.227	3.37	303.673	3.37	300.227	3.37	303.673	3.37	303.673
2008	3.36	310.409	3.37	314.172	3.36	310.409	3.37	314.172	3.37	314.172
2009	3.38	320.83	3.38	324.987	3.38	320.83	3.38	324.987	3.38	324.987
2010	3.41	331.585	3.42	336.181	3.41	331.585	3.42	336.181	3.42	336.181
2011	3.45	342.756	3.46	347.846	2.82	315.899	2.85	322.491	2.67	319.753
2012	3.49	354.412	3.49	359.975	2.82	302.675	2.84	310.872	2.66	306.551
2013	3.52	366.602	3.52	372.617	2.84	290.793	2.85	300.125	2.67	294.491
2014	3.55	379.353	3.55	385.795	2.86	279.963	2.86	290.039	2.69	283.308
2015	3.57	392.674	3.57	399.517	2.89	270.028	2.88	280.566	2.72	272.932
2016	3.58	406.556	3.57	413.79	2.91	260.884	2.90	271.696	2.75	263.333
2017	3.58	420.98	3.57	428.617	2.93	252.462	2.92	263.414	2.79	254.477
2018	3.57	435.929	3.57	444	2.95	244.714	2.95	255.692	2.83	246.317
2019	3.56	451.392	3.55	459.938	2.97	237.597	2.97	248.492	2.87	238.797
2020	3.53	467.365	3.53	476.432	3.00	231.056	2.99	241.772	2.91	231.858

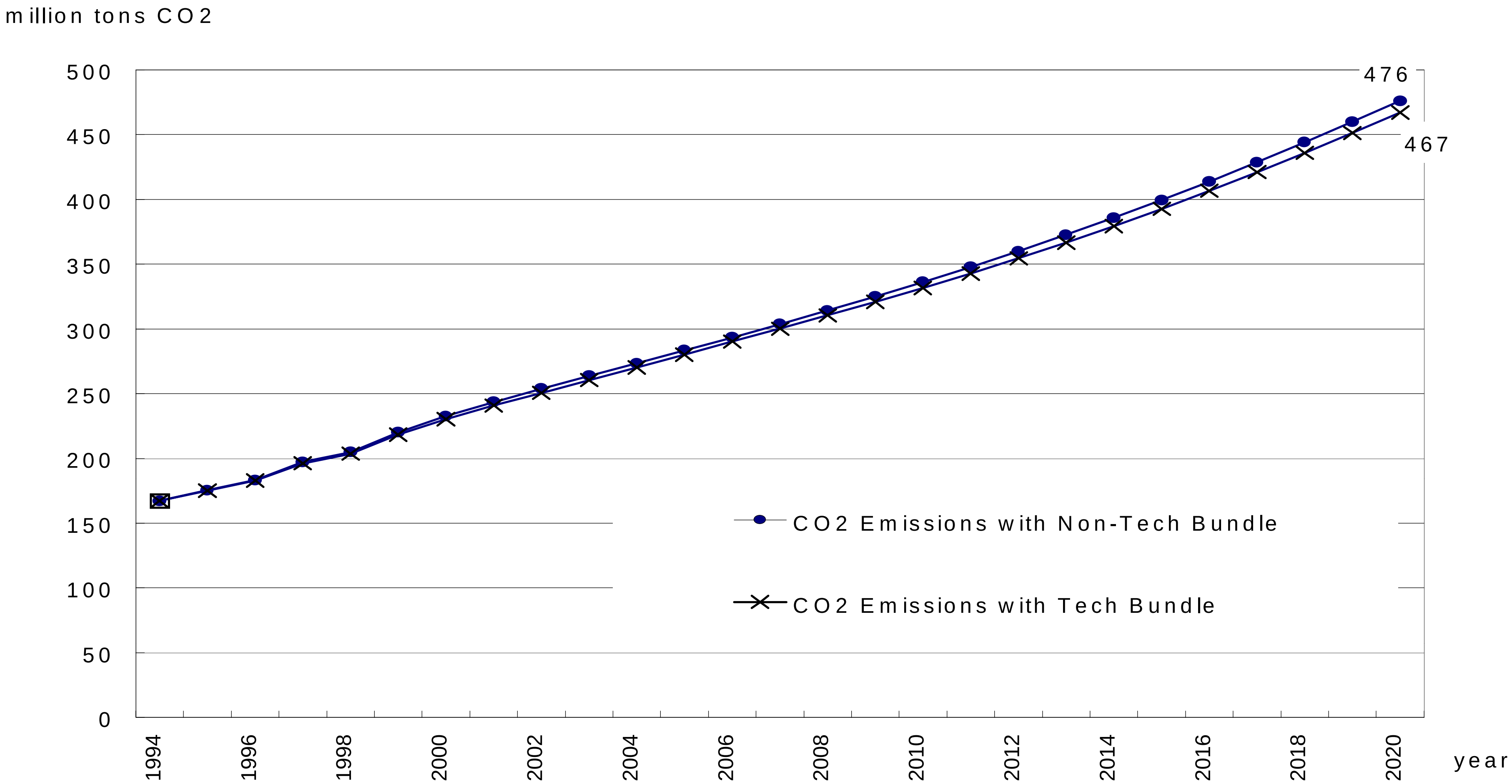

Figure 4. Comparison of CO_2 Emissions Baseline with and without Technology Bundle

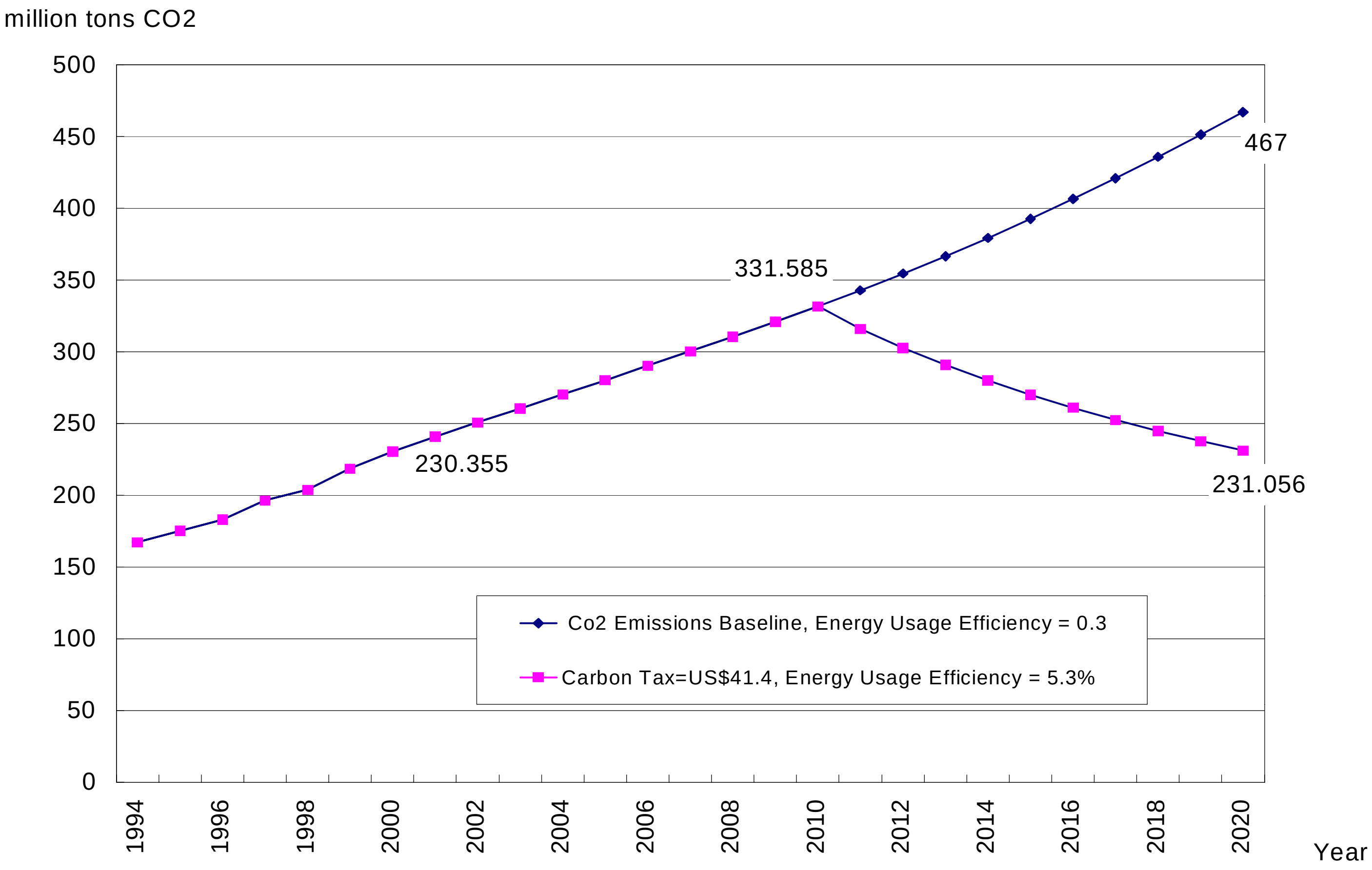

Figure 5. Comparison of CO_2 Emissions with Technology Bundle

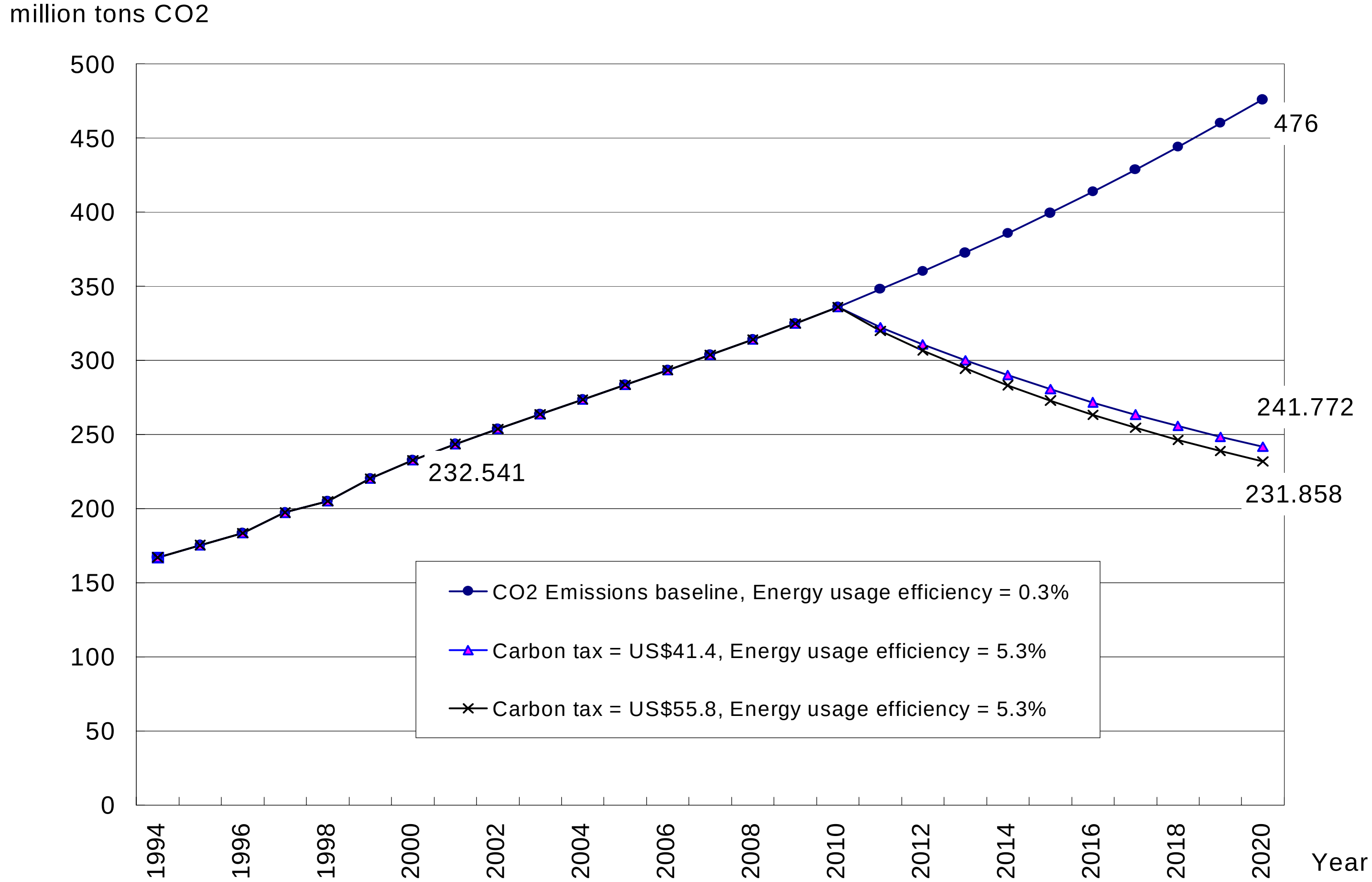

Figure 6. Comparison of CO_2 Emissions without Technology Bundle

Table 2. Energy Structure Projection

Tax unit US$/ton, carbon

	energy usage efficiency = 0.3%		energy usage efficiency = 5.3%			energy usage efficiency = 0.3%		energy usage efficiency = 5.3%			energy usage efficiency = 0.3%		energy usage efficiency= 5.3%		
	baseline		carbon tax scenario			baseline		carbon tax scenario			baseline		carbon tax scenario		
	tech bundle	non-tech bundle	tech bundle	non-tech bundle		tech bundle	non-tech bundle	tech bundle	non-tech bundle		tech bundle	non-tech bundle	tech bundle	non-tech bundle	
			US$41.4	US$41.4	US$55.8			US$41.4	US$41.4	US$55.8			US$41.4	US$41.4	US$55.8
	Coal(%)					**Oil (%)**					**Natural Gas (%)**				
1994*	28.06	28.06	28.06	28.06	28.06	51.44	51.44	51.44	51.44	51.44	5.66	5.66	5.66	5.66	5.66
1995	27.33	27.33	27.33	27.33	27.33	52.51	52.51	52.51	52.51	52.51	5.84	5.84	5.84	5.84	5.84
1996	29.45	29.45	29.45	29.45	29.45	50.31	50.31	50.31	50.31	50.31	5.81	5.81	5.81	5.81	5.81
1997	32.06	32.06	32.06	32.06	32.06	48.27	48.27	48.27	48.27	48.27	6.22	6.22	6.22	6.22	6.22
1998	33.18	33.18	33.18	33.18	33.18	46.72	46.72	46.72	46.72	46.72	7.26	7.26	7.26	7.26	7.26
1999-2000	33.93	33.99	33.93	33.99	33.99	45.84	45.91	45.84	45.91	45.91	7.23	7.23	7.23	7.23	7.23
2001-2005	35.13	35.16	35.13	35.16	35.16	44.45	44.60	44.45	44.60	44.60	7.04	7.03	7.04	7.03	7.03
2006-2010	36.54	36.45	36.54	36.45	36.45	42.82	43.32	42.82	43.32	43.32	6.73	6.83	6.73	6.83	6.83
2011-2015	37.02	37.09	33.81	34.67	34.46	41.73	42.65	41.40	42.70	42.80	6.39	6.64	6.90	6.89	6.97
2016-2020	37.22	37.45	29.50	31.53	31.20	40.95	42.30	38.89	41.61	41.73	6.03	6.45	7.14	7.02	7.18
	Nuclear (%)					**Hydro(%)**									
1994 8	11.82	11.82	11.82	11.82	11.82	3.01	3.01	3.01	3.01	3.01					
1995	11.44	11.44	11.44	11.44	11.44	2.88	2.88	2.88	2.88	2.88					
1996	11.64	11.64	11.64	11.64	11.64	2.79	2.79	2.79	2.79	2.79					
1997	10.64	10.64	10.64	10.64	10.64	2.81	2.81	2.81	2.81	2.81					
1998	9.95	9.95	9.95	9.95	9.95	2.89	2.89	2.89	2.89	2.89					
1999-2000	10.04	9.97	10.04	9.97	9.97	2.95	2.90	2.95	2.90	2.90					
2001-2005	10.23	10.23	10.23	10.23	10.23	3.16	2.98	3.16	2.98	2.98					
2006-2010	10.42	10.37	10.42	10.37	10.37	3.50	3.02	3.50	3.02	3.02					
2011-2015	10.95	10.54	13.20	12.18	12.21	3.91	3.08	4.70	3.55	3.56					
2016-2020	11.50	10.68	17.83	15.36	15.40	4.30	3.12	6.64	4.48	4.49					

*: From year 1994~1999, the energy structure of TAIGEM©-D model is the results of historical simulation.

Table 3. Energy Indexes

	energy usage efficiency = 0.3%		energy usage efficiency = 5.3%			energy usage efficiency = 0.3%		energy usage efficiency = 5.3%		
	baseline		carbon tax scenario			Baseline		carbon tax scenario		
	tech bundle	non-tech bundle	tech bundle	non-tech bundle		tech bundle	non-tech bundle	tech bundle	non-tech bundle	
			US$41.4	US$41.4	US$55.8			US$41.4	US$41.4	US$55.8
	Energy Elasticity					**CO2 Elasticity**				
1994*										
1995	0.73	0.73	0.73	0.73	0.73	0.80	0.81	0.80	0.81	0.81
1996	0.85	0.85	0.85	0.85	0.85	0.78	0.81	0.78	0.81	0.81
1997	0.94	0.94	0.94	0.94	0.94	1.07	1.12	1.07	1.12	1.12
1998	1.16	1.16	1.16	1.16	1.16	0.79	0.81	0.79	0.81	0.81
1999-2000	1.18	1.19	1.18	1.19	1.19	1.12	1.14	1.12	1.14	1.14
2001-2005	1.06	1.06	1.06	1.06	1.06	0.99	1.00	0.99	1.00	1.00
2006-2010	1.07	1.05	1.07	1.05	1.05	1.01	1.02	1.01	1.02	1.02
2011-2015	1.05	1.02	-0.95	-1.01	-1.27	0.98	1.00	-1.41	-1.24	-1.52
2016-2020	1.06	1.02	-0.55	-0.72	-0.85	0.99	1.01	-1.04	-1.00	-1.13
	Energy Intensity					**CO2 Intensity (Fuel Combustion)**				
1994*	10.57	10.57	10.57	10.57	10.57	26.58	24.75	24.75	24.75	24.75
1995	10.40	10.40	10.40	10.40	10.40	26.29	24.50	24.48	24.50	24.50
1996	10.32	10.32	10.32	10.32	10.32	26.00	24.26	24.21	24.26	24.26
1997	10.28	10.28	10.28	10.28	10.28	26.09	24.43	24.29	24.43	24.43
1998	10.35	10.35	10.35	10.35	10.35	25.83	24.21	24.05	24.21	24.21
1999-2000	10.55	10.55	10.55	10.55	10.55	26.28	24.60	24.38	24.60	24.60
2001-2005	10.62	10.64	10.62	10.64	10.64	25.86	24.74	24.45	24.74	24.74
2006-2010	10.76	10.75	10.76	10.75	10.75	24.50	24.97	24.67	24.97	24.97
2011-2015	10.86	10.80	9.10	9.05	8.94	23.25	25.04	19.91	20.54	20.28
2016-2020	10.96	10.83	7.11	6.92	6.76	22.43	25.07	14.47	15.14	14.79

*: From year 1994~1999, the energy index of TAIGEM©-D model is the results of historical simulation.

5. Concluding Remarks

The distinction between a “bottom up” and “top down” approach to modelling the energy sector has received a great deal of attention in recent greenhouse policy debates in Taiwan. One of the most serious criticisms of applied general equilibrium has been the absence of a tractable methodology for restricting energy substitution to known technologies. In this article, we adopted the technology bundle approach proposed in ORANI-E, MEGABARE, and GTEM. The analysis of GHG emission abatement scenarios in this paper is based on simulation results from TAIGEM©(TAIwan General Equilibrium Model), a dynamic, multisectoral, applied general equilibrium model of the Taiwan’s economy, developed specifically to analyze climate change response issues. TAIGEM©-D is derived from the ORANI model (Dixon, Parmenter, Sutton and Vincent, 1982) and the MONASH model.

Results clearly demonstrate that absence of the technology bundle approach in modeling electricity industry leads to overestimation of CO2 baseline projection and, hence, larger carbon tax at the higher expense of GDP loss. Moreover, TAIGEM©-D restricts substitution to known technologies, thereby preventing technically infeasible combinations of inputs being chosen as model solution.

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