The Effect of Carbon Tax and Energy Tax on the Economy of Taiwan, 1999-2020

By

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Abstract

The purpose of this paper is to evaluate and compare the effect of a carbon tax as well as an energy tax on the price levels, output growth, and CO_2 emission by each sector and for the economy as a whole. A dynamic generalized equilibrium model of Taiwan is employed for this evaluation. The major findings of this paper are as follows: 1) To achieve the same policy goal of reducing CO_2 emission by 25.8%, using a one-step approach of implementing a carbon tax will result in an increase of the GDP deflator by 4.51% and a decrease in GDP by 1.01% in 1999. In contrast, the implementation of an energy tax will lead to an increase in the GDP deflator by 4.69 % and a decrease in GDP by 1.04 %. The carbon tax is slightly better than the energy tax owing to its smaller impact on price level and GDP growth under the same CO_2 emission reduction goal. 2) Adopting a progressive Ad Valorem approach, with the same CO_2 emission reduction goal of 25.27%, the implementation of an energy tax will increase the GDP deflator by 2.27% and decrease GDP by 0.88%. Conversely, implementing a carbon tax will increase the GDP deflator by 2.39% and decrease economic growth by 0.93%. 3) Since either a carbon tax or energy tax in a progressive Ad Valorem approach can effectively reduce carbon emission and result in more fiscal income, while minimizing its negative impact on price level and economic growth, employing the progressive Ad Valorem approach instead of the one-step approach is recommended.

1. Introduction

In May 1998, in responding to the new developments after the Kyoto Protocol of December 11, 1997, the government of Taiwan held a Nation-wide Energy Conference. Two important recommendations emerged from this conference: (1) the target for CO_2 reduction should be 24 % to 48 % lower than the BAS (business as usual) projection by 2020; and (2) economic incentives such as carbon tax, energy tax, and emission trading should be considered and carefully examined. The purpose of this paper is to evaluate and to compare the effect of a carbon tax as well as an energy tax on price level, output growth and CO_2 emission by sector and for the economy as a whole.

Policy recommendation will be drawn from the findings. This paper consists of the following four sections: 1. An introduction; 2. The Theoretic Model; 3. The Simulation Methodology and Procedure; 4. Simulation Results and Conclusion.

2. Theoretic Model—Dynamic Generalized Equilibrium Model

The dynamic generalized equilibrium model consists of the following four sub -models: (1) producer's model; (2) consumer's model; (3)DGBAS', macroeconomic model and (4) ITRI's MARKAL-MACRO engineering energy model.

2.1 Producer's Model

The producer's model divides the economy of Taiwan into twenty-nine sectors: eight main sectors (including agriculture, mining, manufacturing, construction, public utility, transportation and service, seventeen manufacturing sectors (excluding oil refinery); and four energy sectors (including coal mining, oil refinery, natural gas and electricity).

We assume that: (1) There exists a twice differentiable aggregate production function relating gross output (Q) to the services of capital (K), labor (L), different types of energy (including coal (C), oil products (O), - namely, gasoline (G), diesel (D), fuel oil (F), and miscellaneous oil products (R), natural gas (N), electricity (E), five kinds of intermediate inputs (including agricultural material (M_1), industrial material (M_2), transportation service intermediate inputs (M_3), service intermediate input (M_4), import material (M_5) and technology (T). (2) The production function is of constant return of scale. (3) Energy inputs, intermediate inputs and oil products in the production function are homothetically weakly separable. (4) Technology (A) is a natural logarithmic function of time (T). Finally, (5) the functional form of the production function is of translog form.

Dual to this production function, the cost function can be written as follows:

$$\ln C = \ln \alpha_* + \alpha_T T + \ln Q + \sum_i \alpha_i \ln P_i + \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j$$
$$+ \sum_i \beta_{iT} \ln P_i T + \frac{1}{2} \beta_{TT} T^2 , \qquad i,j = K,L,E,M \qquad (1)$$

or

$$\ln AC = \ln \alpha_* + \alpha_T T + \sum_i \alpha_i \ln P_i + \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j$$
$$+ \sum_i \beta_{iT} \ln P_i T + \frac{1}{2} \beta_{TT} T^2 , \qquad i,j = K,L,E,M \qquad (2)$$

and

$$\ln P_E = \ln \alpha_* + \sum_i \alpha_i \ln P_i + \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j$$

$$+ \sum_i \beta_{iT} \ln P_i T + \frac{1}{2} \beta_{TT} T^2 \ , \qquad i, j = C, O, N, E \tag{3}$$

$$\ln P_M = \ln \alpha_* + \sum_i \alpha_i \ln P_i + \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j + \sum_i \beta_{iT} \ln P_i T$$

$$+ \frac{1}{2} \beta_{TT} T^2 \ , \qquad i, j = M_1, M_2, M_3, M_4, M_5 \tag{4}$$

$$\ln P_O = \ln \alpha_* + \sum_i \alpha_i \ln P_i + \sum_i \sum_j \beta_{ij} \ln P_i \ln P_j \ , \quad i, j = G, D, F, R \tag{5}$$

where C :   total cost,
AC :   average cost ($=C/Q$),
P_i :   price of i inputs, and,
$\alpha_*, \alpha_T, \alpha_i, \beta_{ij}, \beta_{iT}, \beta_{TT}$, are parameters of the equations.

The last two components, i.e., $\sum \beta_{iT} \ln P_i T$ and $(1/2) \sum \beta_{TT} T^2$ in equation (3) and (4) make our model differs from that of the Hudson-Jorgenson's. They are mainly employed to reflect the time trend of structural changes in sectoral consumptions for energy and intermediate inputs, which are caused by intrasectoral structure changes of sectoral value of production as well as the prevailing changes of sectoral consumption patterns, such as the substitution between oil products and coal.

Since the Hudson-Jorgenson Model is originally designed for highly developed countries, such as the United States, West Germany and Japan, the above modification is essential for applying the model to an economy like Taiwan's, where economic growth is fast and industrial structure change is drastic.

Under minimum cost conditions, equation (1), (3), (4) and (5) represent aggregate input sub-model, energy sub-model, intermediate input sub-model and oil product sub-model respectively. The aggregate input sub-model determines the quantity demanded for capital, labor, aggregate energy and aggregate intermediate input. The energy sub-model determines the quantity demanded for coal, natural gas, oil products and electricity. The intermediate input sub-model determines the quantity demanded for agricultural material, industrial material, transportation service intermediate input, service intermediate input, and import material. The oil products sub-model determines the quantity demanded for gasoline, diesel, fuel, oil and miscellaneous oil products.

Since there are a lot of unknown parameters in the above equations, we estimate the parameters through the following reduced forms to avoid the problem of inadequacy of degree of freedom.

Aggregate Input Sub-model

By Shephard's lemma, a partial differentiation of equation (1) with $\ln P_k$, $\ln P_L$, $\ln P_E$, and $\ln P_M$ yields the following share functions:

$$S_i = \frac{P_i \times Q_i}{C} = \frac{\partial \ln C}{\partial \ln P_i} = \alpha_i + \sum_i \beta_{ij} \ln P_j + \beta_{iT} T \quad i,j = K,L,E,M \quad (6)$$

We define rate of technical change (R_T) as minus growth rate of total cost (C), given prices of input and quantity of production (Q). The minus rate of technical change can be written as

$$-R_T = \frac{\partial \ln AC}{\partial T} = \alpha_T + \beta_{TK} \ln P_K + \beta_{TL} \ln P_L + \beta_{TE} \ln P_E$$
$$+ \beta_{TM} \ln P_M + \beta_{TT} T. \tag{7}$$

In order that equation (6) and (7) satisfy the properties of neoclassical production function theory, the following restrictions are required: (a) Total cost function is a linear homogeneous function of input prices, which indicates

$$\sum_i \alpha_i = 1, \qquad\qquad i=K,L,E,M \qquad\qquad (8)$$

$$\sum_i \beta_{ij} = \sum_i \beta_{ij} = 0, \qquad i,j=K,L,E,M \qquad\qquad (9)$$

$$\sum_i \beta_{iT} = \sum_i \beta_{Tj} = 0, \qquad i,j=K,L,E,M \qquad\qquad (10)$$

$$\sum_i S_i = 1. \qquad\qquad i,j=K,L,E,M ; \qquad\qquad (11)$$

(b) Hessian Matrix is symmetry, which indicates

$$\beta_{ij} = \beta_{ji}. \tag{12}$$

In addition, given the cost function, we can define the biases of technical change with respect to price as derivatives of the value shares with respect to time. Alternatively, we can define the biases of technical change with respect to price as derivatives of the rate of technical change with respect to the logarithms of the price of factors. Those two definitions of biases of technical change are equivalent, namely,

$$\beta_{iT} = \beta_{Ti}, \qquad\qquad i,j=K,L,E,M . \qquad\qquad (13)$$

(c) Since the price functions are increasing in each of the four input prices, the value shares are nonnegative.

$$S_i \geq 0 \qquad\qquad i,j=K,L,E,M \ . \tag{14}$$

(d) Concavity of the translog cost function, which implies that the matrix of second order partial derivatives (Γ), which is called the matrix of constant share elasticities by Jorgenson, is negative semidefinite so that the Hessian matrix is negative semidefinite. This completes the specification of our aggregate input sub-model.

Energy Sub-model

Similarly, by Shephard's lemma, a partial differentiation of equation (3) with respect to $\ln P_C$, $\ln P_O$, $\ln P_N$, and $\ln P_e$, yields the following demand equations for different types of energy in terms of their shares:

$$S_i = \frac{P_i Q_i}{P_E E} = \frac{\partial \ln P_E}{\partial \ln P_i} = \alpha_i + \sum_i \beta_{ij} \ln P_i + \beta_{iT} T \ . \qquad i,j = C,O,N,E. \tag{15}$$

With the only exception of equation (13), the restriction conditions of the parameters in the aggregate input sub-model are also valid in the energy sub-model.

Intermediate Input Sub-model

By Shephard's lemma, a partial differentiation of equation (4) with respect to $\ln P_{M1}$, $\ln P_{M2}$, $\ln P_{M3}$, $\ln P_{M4}$ and $\ln P_{M5}$ yields the following demand equations for various kinds of intermediate inputs in terms of cost shares:

$$S_i = \frac{P_i Q_i}{P_M M} = \frac{\partial \ln P_M}{\partial \ln P_i} = \alpha_i + \sum_i \beta_{ij} \ln P_i + \beta_{iT} T \qquad i,j = M_1,M_2,M_3,M_4,M_5 \tag{16}$$

The restrictions of the parameters in the above equations are similar to those in energy sub-model.

Oil Products Sub-model

Similarly, by Shephard's lemma, partial differentiation of equation (5) with respect to $\ln P_G$, $\ln P_D$, $\ln P_F$, $\ln P_R$ yields the oil products sub-model as follows:

$$S_i = \frac{P_i Q_i}{P_O Q_O} = \frac{\partial \ln P_O}{\partial \ln P_i} = \alpha_i + \sum_i \beta_{ij} \ln P_i \qquad\qquad i,j = G,D,F,R \tag{17}$$

Except for equation (10) the restrictions of the parameters in the above equations are similar to those in the energy sub-model.

Liang (1987), Jorgenson and Liang (1985) and Liang (1999) contain detailed descriptions of this theoretical model, estimation method, data compilation and the

results of coefficients estimated. It is noted that Liang (1999) is a revised model of Jogenson-Liang (1985) with time series data updated from 1961-1981 to 1961-1993, and a combined macro-economic model of the Directorate General of Budget, Accounting & Statistics, Executive Yuan and the MARKAL Engineering Model of the Industrial Technology Research Institute.

2.2 The Consumer's Model

Following Jorgenson and Slesnick (1983), if we assume that the kth household allocates its expenditures in accordance with the translog indirect utility function, the aggregate expenditure shares can be written thus:

$$S = \frac{1}{D(P)}(\alpha_p + \beta_{PP}\ln P - \beta_{PP}i\frac{\sum M_k \ln M_k}{M} + \beta_{PA}\frac{\sum M_k A_k}{M}) \qquad (18)$$

Equation (4) implies that the expenditure shares of the household sector are determined by commodity prices (P), expenditure structure ($(\sum M_k \ln M_k)/M$) and the joint distribution of household expenditure and the attributes ($(\sum M_k A_k)/M$). For a detailed description of the model, please refer to Liang (1990). The consumer's model links with the producer's model through the variable of output prices by sector.

2.3 Macro-Economic Model

The macro-economic model of the Directorate General of Budget Accounting & Statistics consists of 159 equations. We retrieve the following projection data from the Macro-Economic model: (1) GDP growth rate ,(2) wage, (3) interest rate , (4) private consumption and (5) GDP deflator.

2.4 MARKAL Engineering Energy Model

Employing linear programming, the MARKAL model combined the following information to achieve the best energy mix: the growth of industries, the supply of energy, and the energy technologies. We use the aggregate energy demand projected by the MARKAL model to control the total energy consumption with what we got from the producer's and consumer's models in the base projection.

3. The Simulation Methodology and Procedure

The simulation framework of the model is presented in Figure 1, and the simulation of the effect of carbon tax and energy tax of varying types of energy on the economy, are made in the following steps:

Figure 1 The Simulation Framework of Dynamic Generalized Equilibrium Model
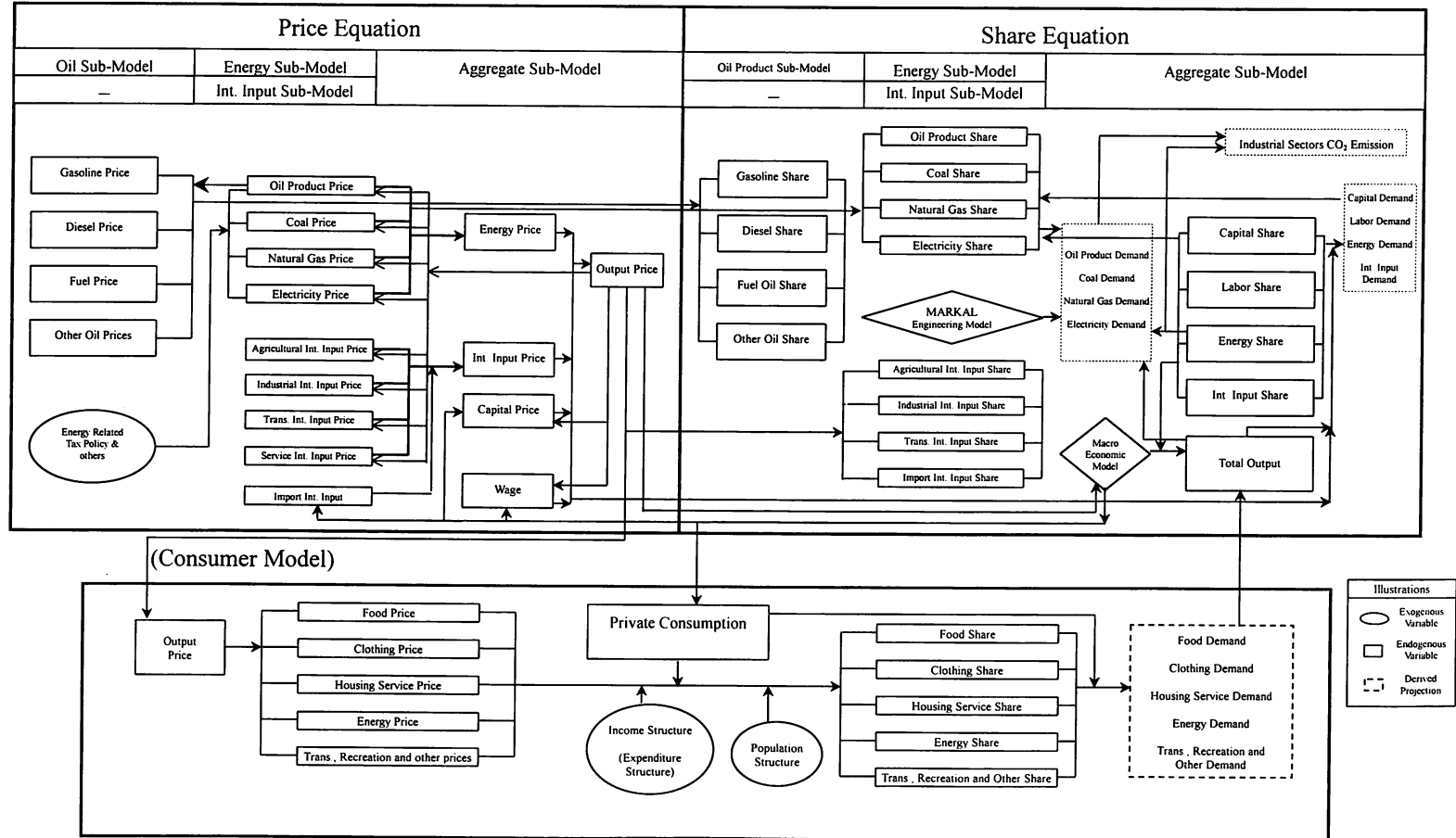
(1) Inserting the projection values of exogenous variables, namely, price of capital service (P_K), wage (P_L) and price of import intermediate input into the producer's model to obtain the base projection of the sectional output growth rates and factor costs shares over 1997-2020. The projection value of P_K, P_L and P_M by sector come from (i) the P_K, P_L, and P_M of the economy as a whole retrieved from the DGBAS macro-economic model, and (ii) the regression result between the P_K, P_L by sector and the P_K, P_L of the whole economy.

(2) The coefficient of different types of energy, taking oil coefficient (O/Q) as an example, can be calculated by the following equation:

$$\frac{O}{Q} = \frac{P_E \cdot E}{P \cdot Q} \cdot \frac{P_o \cdot O}{P_E \cdot E} \cdot \frac{P}{P_o} = S_E \cdot S_o \cdot \frac{P}{P_o}, \tag{19}$$

> where S_E : Energy shares in total cost,
> S_o : Oil share in energy cost,
> P : Output price,
> P_o : Price of oil products.
> S_E, S_o, P and P_o are endogenously determined in the model.

(3) Given the growth rate of sectoral output (Q), the demand for types of energy such as oil product (O) can be obtained by multiplying the oil coefficient (O/Q) with the output (Q). The projected growth rate of sectoral output during 1997-2020 is derived by (i) referring to the sectoral value added growth rate provided by this study, and (ii) employing the sectoral value added share endogenously determined from a simulation of this model.

(4) The amount of CO_2 emission of types of energy can be calculated through the emission factor between consumption of each type of energy and its corresponding CO_2 emission. The emission factor is provided by the Industrial Technology Research Institute (ITRI), such as: coal (3.53 tonCO$_2$/KLOE), oil products (2.89 tonCO$_2$/KLOE, and natural gas (2.09 tonCO$_2$/KLOE). This step completes the whole process for base projection.

(5) Carbon tax cases as well as energy tax cases are calculated. We treat the price of types of energy from endogenous to exogenous ones. We vary prices of energy, implying implementation of carbon tax as well as energy tax, and insert these into the model to calculate their corresponding output prices, cost shares, demand for types of energy and CO_2 emission by sectors.

(6) The results of base projection are compared with those of the carbon tax and the energy tax cases, allowing us to evaluate the impact of different taxation on output price, cost structure and CO_2 emission.

(7) Assuming perfect competition, we measure the impact of energy price changes (due to the changes in taxation or production cost) by the following equation:

$$\frac{\partial \ln Q}{\partial \ln P_i} = \frac{\partial \ln Q}{\partial \ln E} \times \frac{\partial \ln E}{\partial \ln P_E} \times \frac{\partial \ln P_E}{\partial \ln P_i} = S_E \times E_{EE} \times S_i, \quad ^1$$
(20)
$$i = C, O, N, E.$$

Equation (20) implies that the impact of 1.0 percent change in energy price on output is the product of energy share in total cost, price elasticity of demand for energy and i type of energy share in total energy cost.

It is noted that, according to equation (20), the imposition of either a carbon tax or an energy tax will decrease the output growth, which will in turn further reduce the demand for energy and CO_2 emission. Hence, the total impact of a carbon tax as well as an energy tax on CO_2 emission reduction should also take into account its effect on output growth.

4. Simulation Result and Conclusion

4.1 Effect of Carbon Tax on Energy Price:

The percentage of carbon tax amount based on each energy price is shown as follows:

The carbon tax rate of Holland, Finland, Denmark and Sweden, are, respectively, US\$2.24/ton CO_2, US\$3.93/ton CO_2, US\$14.88/ton CO_2 and US\$22.2/ton CO_2. Among all, coal has the highest tax rate, followed by fuel oil, LPG, natural gas, premium diesel oil, gasoline and electricity.

Using as an example the highest carbon tax rate (US\$22.2/ton CO_2), the carbon tax rate of coal is 57.34%, fuel oil 56.16%, LPG 29.65%, natural gas 20.86%, premium diesel oil 17.54%, premium petroleum 11.06% and electricity 8.93%, using Taiwan's energy prices in 1998 as a basis for comparison. The effect of imposing a carbon tax on Taiwan's energy price structure is shown in Table 1. From this Table, we can conclude the following:

(i) Because types of energy are not perfectly substitutable among (e.g. coal and fuel oil cannot replace car-used gasoline and diesel) and the tax rate for each type of energy is different, the unit caloric prices of types of energy are different in Taiwan. The present unit caloric energy price structure is as follows (take unit caloric price of coal as 1) coal : premium gasoline : premium diesel : fuel oil : LPG: natural gas : electricity = 1 : 4.25 : 2.68 : 0.84 : 1.58 : 1.63 : 4.29.

(ii) After imposing a carbon tax, each energy price relative to coal has decreased significantly except fuel oil. Imposing the Swedish carbon tax rate, energy price

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1 $\frac{\partial \ln Q}{\partial \ln E} = \frac{E}{Q} \times \frac{\partial Q}{\partial E} = \frac{E \times MP_E}{Q} = \frac{E \times MP_E \times P}{Q \times P} = \frac{E \times P_E}{Q \times P} = S_E$

ratio (in NT$/LOE) will be changed from the ratio of coal: premium gasoline: premium diesel: fuel oil: LPG: natural gas: electricity = 1: 4.25: 2.68: 0.84: 1.58: 1.63: 4.29 to 1: 3.0: 2.0: 0.83: 1.26: 1.25: 2.97.   This demonstrates the advantage of natural gas, electricity and LPG as substitutes for coal and fuel oil in some sectors.

Table 1. Comparison of Different Carbon Taxes and Energy Prices in 1998

(Unit: NT$ /LOE)

	Coal	Gasoline	Diesel	Fuel	LPG	Natural Gas	Electricity
Price in 1998	4.51	19.15	12.07	3.77	7.14	7.34	19.37
	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
Dutch Tax Rate	0.261	0.214	0.214	0.214	0.214	0.154	0.174
(US$2.44/ton CO$_2$)	(5.786)	(1.116)	(1.770)	(5.667)	(2.992)	(2.105)	(0.901)
Finnish Tax Rate	0.458	0.375	0.375	0.375	0.375	0.271	0.306
(US$3.93/ton CO$_2$)	(10.15)	(1.957)	(3.105)	(9.942)	(5.249)	(3.693)	(1.580)
Danish Tax Rate	1.733	1.419	1.419	1.419	1.419	1.026	1.159
(US$14.88/ton CO$_2$)	(38.43)	(7.410)	(11.76)	(37.64)	(19.88)	(13.98)	(5.983)
Swedish Tax Rate	2.586	2.117	2.117	2.117	2.117	1.531	1.729
(US$22.2/ton CO$_2$)	(57.34)	(11.06)	(17.54)	(56.16)	(29.65)	(20.86)	(8.926)

Note: LOE stands for liter oil equivalent.

4.2 Effect of Carbon Tax on Prices by Sector

One Step Approach

The effect of imposing a carbon tax on prices by sector is shown in Table 2. Because information is limited, tax rates in 1999 are assumed the same as for 1998. From Table 2, we can conclude the following:

(i)   Imposing the highest Swedish tax rate of US$22.2/ton CO$_2$, the water, electricity and gas sector will have the greatest impact on price increase (24.75%) among the seven one-digital sectors, followed by the manufacturing sector (8.79%), the construction sector (5.26%), the mining sector (4.5%), the transportation sector (3.57%), the agriculture sector (3.24%) and the service sector (1.87%). GDP deflator increases 4.51%, which has a relatively large effect on the economy, compared to the 2.0% annual GDP deflator growth rate in recent years.

(ii)   At the same carbon tax rate (US$22.2/ton CO$_2$), the five manufacturing sector with the highest price increases are the following: oil refinery (28.71%); non-metallic mineral (19.52%); textiles (8.87%); basic metal (8.67%); and clothes and wearing apparel (8.24%).

(iii) When the tax rate increases, its effect on manufacturing price increase is not proportional. For example, when the tax rate increases from US$2.24/ton CO$_2$ to US$22.2/ton CO$_2$, a ten-fold increase, the price of the manufacturing sector

increases from 1.12% to 8.79%, only a 7.8-fold increase.

(iv) When the carbon tax amount increases from US$2.24/ton CO_2 to US$22.2/ton CO_2, GDP deflator increases from 0.62% to 4.51%, about a 7.3-fold increase.

Table 2. Effect of Different Carbon Taxes on Price by Sector in 1999

(Unit: %)

	Holland Tax (US$2.44/ ton CO_2)	Finland Tax (US$3.93/ ton CO_2)	Denmark Tax (US$14.88/ ton CO_2)	Sweden Tax (US$22.2/ ton CO_2)
Agriculture	0.4379	0.7473	2.3976	3.2372
Mining	0.5662	0.9710	3.2386	4.5032
Coal Mining	9.5676	16.8312	64.7782	97.6145
Natural Gas	1.0553	1.8446	6.8558	10.1388
Manufacturing	1.1179	1.9149	6.3455	8.7921
Food	0.7297	1.2476	4.0638	5.5444
Beverage & Tobacco	0.7321	1.2516	4.0770	5.5632
Textiles	1.0989	1.8897	6.3599	8.8674
Clothes & Wearing Apparel	1.0320	1.7719	5.9319	8.2378
Leather & Leather Products	0.4822	0.8276	2.7482	3.8029
Wood & Bamboo Products	0.3594	0.6160	2.0449	2.8263
Furniture Products	0.3642	0.6237	2.0690	2.8590
Paper & Printing	0.8972	1.5409	5.1626	7.1785
Chemical & Plastic	0.7947	1.3670	4.6242	6.4651
Rubber Products	0.6711	1.1510	3.8377	5.3158
Oil Refinery	3.4488	5.9492	20.3957	28.7066
Non-Metallic Mineral	2.5675	4.3800	14.2294	19.5230
Basic Metal	1.3634	2.2844	6.7020	8.6669
Metal Products	0.7185	1.2344	4.1465	5.7726
Machinery & Equipment	0.7093	1.2156	4.0564	5.6279
Elect. Mach. & Electronics	0.6762	1.1590	3.8319	5.2818
Transport Equipment	0.6784	1.1634	3.8747	5.3657
Miscellaneous	1.1947	2.0060	5.8386	7.4236
Water, Electricity & Gas	2.9250	5.0515	17.4785	24.7542
Electricity	3.6648	6.3872	23.3686	34.2209
Construction	0.6624	1.1374	3.7929	5.2566
Transportation & Comm.	0.4409	0.7591	2.5650	3.5718
Services	0.3368	0.5623	1.5488	1.8656
Industry	1.1774	2.0199	6.7464	9.3842
GDP Deflator	0.6247	1.0628	3.3600	4.5053

Progressive Ad Valorem Tax Approach

Using a progressive Ad Valorem tax approach, we assume the tax rate for 2020 is the same as for the one step approach in 1999. Each carbon tax rate is shown in Table 1. The effect of carbon tax on prices by sector is shown in Table 3.

**Table 3. Effect of Different Carbon Taxes on Price by Sector
by 2020 -22 Year Progressive Ad Valorem Approach**

(Unit: %)

	Denmark Tax (US$14.88/ ton CO_2)		Sweden Tax (US$22.2/ ton CO_2)	
	2010	2020	2010	2020
Agriculture	0.9804	1.0519	1.3403	1.3238
Mining	1.7682	3.0664	2.4734	4.2399
Coal Mining	30.0036	56.5781	43.6060	85.1998
Natural Gas	4.7779	10.9773	6.9710	16.2314
Manufacturing	2.9907	4.5426	4.1740	6.2605
Food	1.5784	1.8408	2.1759	2.4155
Beverage & Tobacco	1.5907	1.8576	2.1934	2.4373
Textiles	2.7629	3.9666	3.8686	5.4676
Clothes & Wearing Apparel	2.5251	3.5521	3.5266	4.8784
Leather & Leather Products	1.3405	1.9477	1.8700	2.6458
Wood & Bamboo Products	1.0089	1.4135	1.4050	1.9052
Furniture Products	1.0227	1.4339	1.4241	1.9320
Paper & Printing	2.3585	3.5102	3.2947	4.8287
Chemical & Plastic	2.1564	3.2204	3.0314	4.4596
Rubber Products	1.7768	2.5215	2.4735	3.4183
Oil Refinery	11.1159	20.5676	15.6390	28.9475
Non-Metallic Mineral	6.6390	10.4438	9.2105	14.3994
Basic Metal	3.4616	5.4002	4.6587	6.9591
Metal Products	1.9344	2.8352	2.7059	3.8883
Machinery & Equipment	1.8540	2.6552	2.5919	3.6407
Elect. Mach. & Electronics	1.7062	2.2734	2.3670	3.0481
Transport Equipment	1.7628	2.4773	2.4559	3.3605
Miscellaneous	3.1200	4.8953	4.1878	6.2498
Water, Electricity & Gas	8.7794	15.6387	12.3779	22.1362
Electricity	11.5574	20.5989	16.6909	30.0672
Construction	1.6971	2.3920	2.3676	3.2654
Transportation & Comm.	0.9059	0.7169	1.2601	0.8673
Services	0.2825	–	0.3032	–
Industry	3.2091	5.0133	4.4872	6.9451
Whole Economy	1.3115	1.7351	1.7798	2.3916

From this table, we can conclude the following:

(i) Imposing the 22-year progressive Ad Valorem carbon tax of US$22.2/ton CO_2), the water, electricity and gas sector (22.14%) will be affected the greatest in price increase among the seven one digital sectors. These are followed by the manufacturing sector (6.26%), the mining sector (4.24%), the construction sector (3.27%), the agriculture sector (1.32%) and the transportation sector (0.87%).

(ii) At the same carbon tax rate, the five manufacturing sectors with the highest price increase are oil refinery (28.95%), non-metallic mineral (14.40%), basic metal (6.96%), miscellaneous (6.25%) and textiles (5.47%).

(iii) When carbon tax increases, its impact on prices will not proportionally increase in

the manufacturing sector. For example, when the tax rate increases 50%, manufacturing sector price increases only 38%, i.e. from 4.54% to 6.26% by 2020.

(iv) When carbon tax rate increases 50%, the GDP deflator in 2020 will increase 38%, i.e. from 1.74% to 2.39%.

(v) Comparing Table 2 and 3, we found that the progressive Ad Valorem tax approach can effectively reduce the negative effect on the price level. For instance, at the same Swedish carbon tax rate of US$22.2/ton CO_2, using one step approach will increase the GDP deflator by 4.51%, while using a 22-year progressive approach will increase the GDP deflator by 2.39%, about half of that obtained by using the one step approach.

4.3 Effect of Carbon Tax on Output Growth

One Step Approach

The effect of a carbon tax on output growth is shown in Table 4 (Dutch tax rate), Table 5 (Finnish tax rate), Table 6 (Danish tax rate) and Table 7 (Swedish tax rate). From the above tables, we conclude the following:

(i) The effect of a carbon tax on output growth is through price increases in types of energy. Among them, the effect of an increase in oil price is the greatest. For example, in the case where the Swedish carbon tax of US$22.2/ton CO_2 is imposed on oil, output will decrease by 0.63%, followed by coal at (-0.21%), electricity at (-0.12%) and natural gas at (-0.05%). The total effect of imposing a carbon tax on output growth is -1.01 percentage point.

(ii) Among seven one-digital sectors, imposing a carbon tax has the largest effect on the output growth of water, electricity and gas sector. For example, when the carbon tax is US$22.2/ton CO_2, the output of water, electricity and gas will decrease by 11.29%, followed by decreases in these sectors: mining (-4.20%); transportation (-2.0%); manufacturing (-1.57%); agriculture (-1.17%); construction (-0.72%); and service (-0.22%).

(iii) The largest effect on output growth of imposing the same tax rate in the manufacturing sectors would be on oil refinery (-8.77%), miscellaneous (-6.91%), non-metallic mineral (-3.32%), basic metal (-2.21%) and chemical and plastic (-1.86%).

(iv) As the tax rate increases, the negative effect of a carbon tax on output growth will increase proportionally. When the carbon tax rate increases from US$2.24/ton CO_2 (Dutch tax rate) to US$22.2/ton CO_2 (Swedish tax rate), the reduction of GDP growth rate will decrease from 0.103 percentage point to 1.01 percentage point.

Table 4. Effect of Carbon Taxes (US$22.2/ton CO₂) on Output Growth in 1999 (One Step Approach)

(Unit: %)

	(1) Tax Effect on Coal	(2) Tax Effect on Oil	(3) Tax Effect on Natural Gas	(4) Tax Effect on Electricity	Total Effect
Agriculture	0.0000	-0.1109	0.0000	-0.0071	-0.1180
Mining	-0.1029	-0.2971	-0.0185	-0.0209	-0.4394
Coal Mining	-0.0142	-0.0279	0.0000	-0.0443	-0.0864
Natural Gas	0.0000	-0.0616	-0.1170	-0.0161	-0.1947
Manufacturing	-0.0427	-0.0831	-0.0096	-0.0205	-0.1559
Food	-0.0010	-0.0225	-0.0004	-0.0110	-0.0348
Beverage & Tobacco	-0.0014	-0.0506	-0.0005	-0.0096	-0.0621
Textiles	-0.0002	-0.0407	-0.0002	-0.0310	-0.0720
Clothes & Wearing Apparel	-0.0009	-0.0250	0.0000	-0.0100	-0.0359
Leather & Leather Products	-0.0003	-0.0219	0.0000	-0.0131	-0.0353
Wood & Bamboo Products	0.0000	-0.0304	-0.0001	-0.0202	-0.0507
Furniture Products	0.0000	-0.0301	-0.0001	-0.0200	-0.0502
Paper & Printing	-0.0045	-0.0547	-0.0005	-0.0430	-0.1027
Chemical & Plastic	-0.0102	-0.1495	-0.0024	-0.0294	-0.1914
Rubber Products	-0.0003	-0.0470	0.0000	-0.0183	-0.0656
Oil Refinery	-0.0143	-0.8590	-0.0112	-0.0020	-0.8865
Non-Metallic Mineral	-0.1210	-0.1631	-0.0199	-0.0295	-0.3335
Basic Metal	-0.3831	-0.2079	-0.0093	-0.1081	-0.7085
Metal Products	-0.0055	-0.0302	-0.0004	-0.0168	-0.0530
Machinery & Equipment	-0.0042	-0.0295	-0.0003	-0.0112	-0.0452
Elect. Mach. & Electronics	-0.0004	-0.0112	-0.0007	-0.0092	-0.0216
Transport Equipment	-0.0006	-0.0167	-0.0008	-0.0066	-0.0247
Miscellaneous	-0.0007	-0.0631	-0.0003	-0.0369	-0.1010
Water, Electricity & Gas	-0.4035	-0.6209	-0.0895	-0.1101	-1.2241
Electricity	-0.3420	-0.4314	-0.0488	-0.0902	-0.9124
Construction	-0.0243	-0.0453	0.0000	-0.0020	-0.0716
Transportation & Comm.	-0.0003	-0.1941	0.0000	-0.0080	-0.2024
Services	0.0000	-0.0156	-0.0001	-0.0066	-0.0223
Industry	-0.5734	-1.0464	-0.1176	-0.1536	-1.8909
Whole Economy	-0.0218	-0.0641	-0.0047	-0.0126	-0.1032

Table 5. Effect of Carbon Taxes (US$3.93/ ton CO₂) on Output Growth in 1999 (One Step Approach)

(Unit: %)

	(1) Tax Effect on Coal	(2) Tax Effect on Oil	(3) Tax Effect on Natural Gas	(4) Tax Effect on Electricity	Total Effect
Agriculture	0.0000	-0.1944	0.0000	-0.0125	-0.2069
Mining	-0.1804	-0.5181	-0.0324	-0.0370	-0.7679
Coal Mining	-0.0250	-0.0489	0.0000	-0.0777	-0.1516
Natural Gas	0.0000	-0.1078	-0.2054	-0.0282	-0.3414
Manufacturing	-0.0750	-0.1462	-0.0169	-0.0359	-0.2739
Food	-0.0017	-0.0394	-0.0007	-0.0194	-0.0611
Beverage & Tobacco	-0.0025	-0.0888	-0.0009	-0.0168	-0.1090
Textiles	-0.0003	-0.0717	-0.0003	-0.0543	-0.1265
Clothes & Wearing Apparel	-0.0016	-0.0438	0.0000	-0.0175	-0.0630
Leather & Leather Products	-0.0006	-0.0389	0.0000	-0.0228	-0.0623
Wood & Bamboo Products	0.0000	-0.0534	-0.0002	-0.0355	-0.0891
Furniture Products	0.0000	-0.0529	-0.0002	-0.0351	-0.0881
Paper & Printing	-0.0079	-0.0959	-0.0008	-0.0755	-0.1801
Chemical & Plastic	-0.0168	-0.2630	-0.0037	-0.0518	-0.3352
Rubber Products	-0.0004	-0.0824	0.0000	-0.0321	-0.1150
Oil Refinery	-0.0251	-1.5065	-0.0199	-0.0034	-1.5549
Non-Metallic Mineral	-0.2122	-0.2859	-0.0358	-0.0515	-0.5854
Basic Metal	-0.6116	-0.3440	-0.0153	-0.1785	-1.1494
Metal Products	-0.0096	-0.0530	-0.0008	-0.0295	-0.0929
Machinery & Equipment	-0.0074	-0.0517	-0.0005	-0.0196	-0.0793
Elect. Mach. & Electronics	-0.0007	-0.0197	-0.0013	-0.0161	-0.0378
Transport Equipment	-0.0010	-0.0293	-0.0014	-0.0115	-0.0432
Miscellaneous	-0.0090	-0.7642	-0.0037	-0.4462	-1.2231
Water, Electricity & Gas	-0.7055	-1.0824	-0.1565	-0.1923	-2.1367
Electricity	-0.6021	-0.7524	-0.0858	-0.1583	-1.5985
Construction	-0.0426	-0.0796	0.0000	-0.0035	-0.1257
Transportation & Comm.	-0.0006	-0.3404	0.0000	-0.0141	-0.3551
Services	-0.0001	-0.0274	-0.0003	-0.0115	-0.0392
Industry	-0.1152	-0.2070	-0.0245	-0.0426	-0.3893
Whole Economy	-0.0382	-0.1125	-0.0083	-0.0220	-0.1810

Table 6. Effect of Carbon Taxes (US$14.88/ton CO₂) on Output Growth in 1999 (One Step Approach)

(Unit %)

	(1) Tax Effect on Coal	(2) Tax Effect on Oil	(3) Tax Effect on Natural Gas	(4) Tax Effect on Electricity	Total Effect
Agriculture	0.0000	-0.7343	0.0000	-0.0478	-0.7821
Mining	-0.6792	-1.8970	-0.1223	-0.1478	-2.8462
Coal Mining	-0.0945	-0.1852	0.0000	-0.2944	-0.5741
Natural Gas	0.0000	-0.4011	-0.7802	-0.1063	-1.2875
Manufacturing	-0.2838	-0.5620	-0.0649	-0.1342	-1.0450
Food	-0.0064	-0.1491	-0.0026	-0.0733	-0.2313
Beverage & Tobacco	-0.0095	-0.3360	-0.0035	-0.0635	-0.4126
Textiles	-0.0010	-0.2753	-0.0010	-0.2050	-0.4824
Clothes & Wearing Apparel	-0.0062	-0.1668	0.0000	-0.0659	-0.2389
Leather & Leather Products	-0.0022	-0.1593	0.0000	-0.0839	-0.2454
Wood & Bamboo Products	0.0000	-0.2030	-0.0006	-0.1347	-0.3383
Furniture Products	0.0000	-0.2008	-0.0006	-0.1333	-0.3347
Paper & Printing	-0.0298	-0.3632	-0.0030	-0.2858	-0.6818
Chemical & Plastic	-0.0393	-1.0117	-0.0034	-0.2021	-1.2565
Rubber Products	-0.0017	-0.3118	0.0000	-0.1217	-0.4353
Oil Refinery	-0.0952	-5.6910	-0.0822	-0.0121	-5.8805
Non-Metallic Mineral	-0.8036	-1.0786	-0.1520	-0.1884	-2.2226
Basic Metal	-1.1832	-0.8208	-0.0347	-0.4230	-2.4618
Metal Products	-0.0364	-0.2006	-0.0029	-0.1119	-0.3518
Machinery & Equipment	-0.0282	-0.1966	-0.0023	-0.0746	-0.3017
Elect. Mach. & Electronics	-0.0028	-0.0746	-0.0049	-0.0609	-0.1432
Transport Equipment	-0.0037	-0.1106	-0.0054	-0.0433	-0.1630
Miscellaneous	-0.0341	-2.8933	-0.0141	-1.6896	-4.6311
Water, Electricity & Gas	-2.6119	-3.9446	-0.5777	-0.7083	-7.8424
Electricity	-2.3219	-2.7552	-0.3286	-0.6026	-6.0083
Construction	-0.1624	-0.3033	0.0000	-0.0134	-0.4791
Transportation & Comm.	-0.0022	-1.2881	0.0000	-0.0534	-1.3436
Services	-0.0003	-0.1044	-0.0010	-0.0440	-0.1496
Industry	-0.4323	-0.7795	-0.0926	-0.1588	-1.4632
Whole Economy	-0.1434	-0.4248	-0.0312	-0.0827	-0.6821

Table 7. Effect of Carbon Taxes (US$22.2/ton CO₂) on Output Growth in 1999 (One Step Approach)

(Unit %)

	(1) Tax Effect on Coal	(2) Tax Effect on Oil	(3) Tax Effect on Natural Gas	(4) Tax Effect on Electricity	Total Effect
Agriculture	0.0000	-1.0940	0.0000	-0.0716	-1.1656
Mining	-1.0098	-2.7788	-0.1820	-0.2263	-4.1970
Coal Mining	-0.1411	-0.2763	0.0000	-0.4392	-0.8565
Natural Gas	0.0000	-0.5924	-1.1663	-0.1580	-1.9167
Manufacturing	-0.4234	-0.8457	-0.0977	-0.1987	-1.5655
Food	-0.0095	-0.2225	-0.0038	-0.1093	-0.3451
Beverage & Tobacco	-0.0141	-0.5013	-0.0053	-0.0948	-0.6155
Textiles	-0.0015	-0.4140	-0.0015	-0.3054	-0.7224
Clothes & Wearing Apparel	-0.0092	-0.2495	0.0000	-0.0979	-0.3567
Leather & Leather Products	-0.0032	-0.2472	0.0000	-0.1231	-0.3735
Wood & Bamboo Products	0.0000	-0.3033	-0.0009	-0.2013	-0.5055
Furniture Products	0.0000	-0.3001	-0.0009	-0.1991	-0.5001
Paper & Printing	-0.0445	-0.5418	-0.0045	-0.4264	-1.0171
Chemical & Plastic	-0.0382	-1.5181	0.0000	-0.3056	-1.8619
Rubber Products	-0.0025	-0.4652	0.0000	-0.1816	-0.6493
Oil Refinery	-0.1420	-8.4800	-0.1285	-0.0173	-8.7677
Non-Metallic Mineral	-1.1989	-1.6064	-0.2394	-0.2761	-3.3208
Basic Metal	-0.9934	-0.7805	-0.0321	-0.4008	-2.2068
Metal Products	-0.0543	-0.2993	-0.0043	-0.1669	-0.5248
Machinery & Equipment	-0.0422	-0.2940	-0.0036	-0.1114	-0.4511
Elect. Mach. & Electronics	-0.0042	-0.1112	-0.0073	-0.0908	-0.2135
Transport Equipment	-0.0055	-0.1646	-0.0080	-0.0644	-0.2425
Miscellaneous	-0.0509	-4.3167	-0.0210	-2.5207	-6.9093
Water, Electricity & Gas	-3.7753	-5.6607	-0.8336	-1.0215	-11.2911
Electricity	-3.4969	-4.0366	-0.4926	-0.9017	-8.9279
Construction	-0.2432	-0.4542	0.0000	-0.0200	-0.7173
Transportation & Comm.	-0.0032	-1.9208	0.0000	-0.0795	-2.0036
Services	-0.0004	-0.1562	-0.0015	-0.0659	-0.2240
Industry	-0.6368	-1.1530	-0.1370	-0.2334	-2.1602
Whole Economy	-0.2112	-0.6306	-0.0462	-0.1224	-1.0104

Progressive Ad Valorem Tax Approach

Using a progressive Ad Valorem approach, the tax rate in 2020 would be the same as if one step approach were used in 1999. The effect of carbon tax on output growth is shown in Table 8 (carbon tax: US$14.88/ton CO_2 in 1999) and Table 9 (carbon tax: US$22.2/ton CO_2 in 1999).

Table 8. Effect of Carbon Taxes (US$14.88/ton CO_2) on Output Growth in 2020 (22-year Progressive Ad Valorem Tax Approach)

(Unit %)

	(1) Tax Effect on Coal	(2) Tax Effect on Oil	(3) Tax Effect on Natural Gas	(4) Tax Effect on Electricity	Total Effect
Agriculture	0.0000	-0.7731	0.0000	-0.1024	-0.8755
Mining	-0.5799	-1.7124	-0.1035	-0.1119	-2.5077
Coal Mining	-0.0684	-0.1339	0.0000	-0.2129	-0.4152
Natural Gas	0.0000	-0.7921	-1.3940	-0.2160	-2.4021
Manufacturing	-0.2283	-0.4554	-0.0586	-0.1047	-0.8471
Food	-0.0088	-0.0778	-0.0066	-0.1211	-0.2144
Beverage & Tobacco	-0.0125	-0.2946	-0.0082	-0.1060	-0.4213
Textiles	-0.0015	-0.2615	-0.0015	-0.3236	-0.5881
Clothes & Wearing Apparel	-0.0113	-0.2380	0.0000	-0.1309	-0.3802
Leather & Leather Products	-0.0053	-0.0608	-0.0002	-0.2546	-0.3209
Wood & Bamboo Products	-0.0008	-0.3906	-0.0011	-0.2591	-0.6515
Furniture Products	-0.0007	-0.3786	-0.0011	-0.2511	-0.6315
Paper & Printing	-0.0270	-0.2012	-0.0027	-0.2791	-0.5101
Chemical & Plastic	0.0000	-0.7500	0.0000	-0.1545	-0.9045
Rubber Products	-0.0048	0.0000	0.0000	-0.2101	-0.2149
Oil Refinery	-0.0770	-4.6377	-0.0196	-0.0248	-4.7592
Non-Metallic Mineral	-0.6249	-0.8005	-0.0720	-0.1724	-1.6698
Basic Metal	-4.4148	-1.0459	-0.0917	-0.9509	-6.5034
Metal Products	-0.0427	-0.1437	-0.0028	-0.1167	-0.3059
Machinery & Equipment	-0.0382	-0.2663	-0.0018	-0.1016	-0.4079
Elect. Mach. & Electronics	-0.0060	-0.1048	-0.0009	-0.1299	-0.2416
Transport Equipment	-0.0005	-0.0085	-0.0006	-0.0054	-0.0150
Miscellaneous	–	–	–	–	–
Water, Electricity & Gas	-4.2560	0.0000	-0.6317	-1.0873	-5.9750
Electricity	-3.4168	0.0000	-0.3659	-0.8637	-4.6464
Construction	-0.2590	-0.3969	0.0000	-0.0351	-0.6910
Transportation & Comm.	-0.0026	-1.5343	0.0000	-0.0708	-1.6077
Services	-0.0004	-0.1047	-0.0023	-0.0607	-0.1681
Industry	-0.5087	-0.4367	-0.0910	-0.1628	-1.1993
Whole Economy	-0.1687	-0.3293	-0.0314	-0.0963	-0.6258

Table 9. Effect of Carbon Taxes (US$22.2/ton CO$_2$) on Output Growth in 2020 (22-year Progressive Ad Valorem Tax Approach)

(Unit %)

	(1) Tax Effect on Coal	(2) Tax Effect on Oil	(3) Tax Effect on Natural Gas	(4) Tax Effect on Electricity	Total Effect
Agriculture	0.0000	-1.1509	0.0000	-0.1532	-1.3041
Mining	-0.8609	-2.5073	-0.1538	-0.1715	-3.6935
Coal Mining	-0.1020	-0.1998	0.0000	-0.3176	-0.6194
Natural Gas	0.0000	-1.1702	-2.0837	-0.3211	-3.5749
Manufacturing	-0.3407	-0.6845	-0.0880	-0.1552	-1.2684
Food	-0.0132	-0.1161	-0.0099	-0.1807	-0.3199
Beverage & Tobacco	-0.0186	-0.4396	-0.0123	-0.1581	-0.6286
Textiles	-0.0022	-0.3952	-0.0023	-0.4819	-0.8816
Clothes & Wearing Apparel	-0.0168	-0.3572	0.0000	-0.1947	-0.5687
Leather & Leather Products	-0.0079	-0.0906	-0.0003	-0.3791	-0.4778
Wood & Bamboo Products	-0.0011	-0.5829	-0.0017	-0.3866	-0.9724
Furniture Products	-0.0011	-0.5650	-0.0016	-0.3747	-0.9425
Paper & Printing	-0.0403	-0.3002	-0.0041	-0.4164	-0.7610
Chemical & Plastic	0.0000	-1.1184	0.0000	-0.2306	-1.3490
Rubber Products	-0.0073	0.0000	0.0000	-0.3134	-0.3207
Oil Refinery	-0.1149	-6.9190	-0.0308	-0.0364	-7.1011
Non-Metallic Mineral	-0.9323	-1.1932	-0.1160	-0.2537	-2.4951
Basic Metal	-5.7314	-1.5394	-0.1276	-1.3575	-8.7559
Metal Products	-0.0637	-0.2144	-0.0042	-0.1741	-0.4563
Machinery & Equipment	-0.0570	-0.3973	-0.0029	-0.1514	-0.6085
Elect. Mach. & Electronics	-0.0089	-0.1561	-0.0013	-0.1935	-0.3599
Transport Equipment	-0.0006	-0.0116	-0.0008	-0.0073	-0.0203
Miscellaneous	–	–	–	–	–
Water, Electricity & Gas	-6.2605	0.0000	-0.9265	-1.5963	-8.7833
Electricity	-5.1069	0.0000	-0.5446	-1.2849	-6.9364
Construction	-0.3870	-0.5930	0.0000	-0.0525	-1.0324
Transportation & Comm.	-0.0039	-2.2890	0.0000	-0.1056	-2.3985
Services	-0.0006	-0.1562	-0.0035	-0.0906	-0.2508
Industry	-0.7530	-0.6551	-0.1351	-0.2404	-1.7836
Whole Economy	-0.2498	-0.4924	-0.0467	-0.1428	-0.9316

From these tables, we can conclude the following:

(i)   The effect of a carbon tax on output growth is channeled through price increases in four types of energy. Among them, the effect resulting from an oil price increase is the greatest. When the Swedish carbon tax of US$22.2/ton CO$_2$ is imposed on oil, the GDP growth rate will decrease by 0.49 percentage points in 2020. A coal price increase would cause a decrease in GDP growth rate of 0.25%, while electricity and natural gas price increases would produce figure of -0.14% and -0.05% respectively. The total effect of imposing the Swedish carbon tax of

US$22.2/ton CO_2 on GDP growth is -0.93 percentage.

(ii)   Imposing a carbon tax has the largest effect on the output growth of the water, electricity and gas sector among the seven one-digital sectors. For example, when the Swedish carbon tax rate is US$22.2/ton CO_2, the output growth of water, electricity and gas will decrease 8.78 percentage points by 2020. Tax on the following sectors would produce these output decrease: mining (-3.69%); transportation (-2.40%); agriculture (-1.30%); manufacturing (-1.27%); construction (-1.03%); and service (-0.25%).

(iii) If the same carbon tax rate is imposed on the top five manufacturing sectors would experience the following output decreases: basic metal (-8.76%); oil refinery (-7.10%); non-metallic mineral (-2.50%); chemical and plastic (-1.35%); and wood and bamboo products (-0.97%).

4.4 Effect of Carbon Tax on Energy Demand and CO_2 Emission

One Step Approach

The effect of a carbon tax on energy demand and CO_2 emission is shown in Table 10. From this table, we can conclude the following:

(i)   If a Dutch carbon tax (US$2.24/ton CO_2) is imposed in the one step approach, CO_2 emission decreases 3.95% in 1999. Demand for coal decreases most, at -7.67%, followed by electricity (-2.82%), oil (-2.52%) and natural gas (-0.486%).

(ii)   Imposing a carbon tax by using the one step approach has the largest effect on energy demand and CO_2 emission in the mining sector. For example, when the Dutch carbon tax is US$2.24/ton CO_2, the CO_2 emission of the construction sector decreases 6.02%, followed by mining (-5.94%), water, electricity and gas (-4.79%), manufacturing (-4.34%), transportation (-3.14%), agriculture (-3.08%) and service (-3.02%).

(iii) If the same tax rate is imposed, the top five manufacturing sectors with the largest effect on CO_2 emission are basic metal (-15.28%), non-metallic mineral (-3.94%), chemical and plastic (-3.50%), metal products (-3.41%) and machinery and equipment (-3.32%).

Progressive Ad Valorem Tax Approach

The effects of imposing a 22-year progressive Ad Valorem carbon tax on energy demand and CO_2 emission are shown in Tables 11 and 12. From Table 12, we conclude the following:

(i)   Imposing a progressive Ad Valorem Swedish carbon tax rate of US$22.2/ton CO_2 will bring about a decrease in CO_2 of 25.71% by 2020. Energy demand for coal decreases most, at a rate of -42.24%, followed by electricity (-21.34%), oil

(-20.13%) and natural gas (-6.56%). The tax effect on reducing CO_2 emission and energy demand is remarkable.

(ii) Imposing a carbon tax has the largest effect on energy demand and CO_2 emission reduction in the construction sector. For example, when the Swedish carbon tax is US$22.2/ton CO_2, the CO_2 emission of the construction sector decreases 35.97% in 2020, followed by these sectors: mining (-35.67%), water, electricity and gas (-33.89%), manufacturing (-27.53%), service (-24.49%), transportation (-24.3%) and agriculture (-23.02%).

(iii) With a 22-year progressive Ad Valorem tax approach, when the tax rate increases from US$14.88/ton CO_2 to US$22.2/ton CO_2, a 50% increase, the CO_2 emission reduction rate will increase from -19.43 percentage point to -25.71 percentage points, a 32% increase.

Table 10. Effect of Carbon Taxes (US$2.24/ton CO_2) on Energy Demand and CO_2 Emission in 1999

(Unit: %)

	(1) Coal	(2) Oil	(3) Nature Gas	(4) Electricity	(5) CO_2
Agriculture	0.000	-2.962	0.000	-2.954	-3.078
Mining	-8.337	-3.601	-0.564	-1.556	-5.938
Coal Mining	–	–	–	–	–
Natural Gas	0.000	-2.716	0.078	-2.648	-1.680
Manufacturing	-7.712	-1.870	0.465	-2.779	-4.335
Food	-8.066	-2.628	-0.322	-2.831	-2.952
Beverage & Tobacco	-8.064	-2.626	-0.320	-2.829	-2.940
Textiles	-7.729	-1.910	0.043	-2.550	-2.444
Clothes & Wearing Apparel	-7.876	-2.206	0.000	-2.718	-2.703
Leather & Leather Products	-8.378	-0.762	142.747	-3.730	-2.812
Wood & Bamboo Products	0.000	-2.908	-0.608	-3.111	-3.095
Furniture Products	0.000	-2.912	-0.613	-3.115	-3.098
Paper & Printing	-7.913	-2.465	-0.157	-2.670	-2.953
Chemical & Plastic	-15.407	-2.178	-14.261	-2.015	-3.504
Rubber Products	-8.120	-2.697	0.000	-2.883	-2.891
Oil Refinery	-5.584	-0.053	4.657	-1.829	-1.100
Non-Metallic Mineral	-6.389	-0.945	5.008	-1.925	-3.942
Basic Metal	-18.210	-9.009	-8.058	-9.368	-15.282
Metal Products	-8.076	-2.639	-0.333	-2.842	-3.439
Machinery & Equipment	-7.978	-2.535	2.787	-2.771	-3.317
Elect. Mach. & Electronics	-8.092	-2.656	-0.350	-2.858	-2.910
Transport Equipment	-8.197	-2.767	-0.464	-2.970	-3.032
Miscellaneous	–	–	–	–	–
Water, Electricity & Gas	-6.486	-1.370	1.353	-1.307	-4.788
Electricity	-4.938	-0.606	2.928	0.132	-3.391
Construction	-7.967	-2.523	0.000	-2.726	-6.024
Transportation & Comm.	-8.337	-2.915	0.000	-3.129	-3.143
Services	-8.245	-2.818	-0.516	-3.020	-3.019
Industry	-7.671	-1.866	0.498	-2.747	-6.067
Whole Economy	-7.672	-2.520	0.486	-2.822	-3.948

Table 11. Effect of Carbon Taxes (US\$14.88/ton CO$_2$) on Energy Demand and CO$_2$ Emission by 2020(22 Year Progressive Ad Valorem Tax Approach)

(Unit: %)

	(1) Coal	(2) Oil	(3) Nature Gas	(4) Electricity	(5) CO$_2$
Agriculture	0.0000	-16.596	0.0000	-15.674	-17.061
Mining	-34.932	-18.487	-7.994	-7.333	-27.164
Coal Mining	–	–	–	–	–
Natural Gas	-100.000	-6.853	-0.183	-8.934	-7.646
Manufacturing	-33.233	-11.581	-4.306	-14.771	-20.914
Food	-34.958	-15.532	-8.233	-15.554	-16.433
Beverage & Tobacco	-34.948	-15.518	-8.218	-15.540	-16.647
Textiles	-33.601	-10.734	-6.317	-14.166	-14.109
Clothes & Wearing Apparel	-34.023	-12.801	0.0000	-14.768	-15.113
Leather & Leather Products	-35.144	-15.774	28.771	-15.804	-16.357
Wood & Bamboo Products	-27.302	-15.789	-8.512	-15.815	-16.468
Furniture Products	-27.389	-15.779	-8.501	-15.805	-16.437
Paper & Printing	-33.892	-14.148	-6.728	-14.170	-15.618
Chemical & Plastic	-100.000	-14.560	0.0000	-13.904	-15.602
Rubber Products	-29.368	0.0000	0.0000	-15.012	-15.420
Oil Refinery	-23.468	0.141	8.642	-3.769	-5.416
Non-Metallic Mineral	-29.464	-8.633	27.859	-11.751	-20.426
Basic Metal	-50.991	-11.540	-18.726	-19.555	-48.786
Metal Products	-34.323	-14.707	-7.337	-14.730	-17.843
Machinery & Equipment	-34.394	-14.799	17.013	-14.956	-17.524
Elect. Mach. & Electronics	-34.806	-15.335	-8.018	-15.357	-16.037
Transport Equipment	-45.293	-28.954	-22.814	-28.972	-29.473
Miscellaneous	–	–	–	–	–
Water, Electricity & Gas	-28.455	-7.490	0.342	-7.721	-25.039
Electricity	-22.548	-0.258	8.399	-0.801	-17.690
Construction	-34.331	-14.717	0.0000	-14.739	-27.698
Transportation & Comm.	-35.690	-16.466	0.0000	-16.679	-18.128
Services	-36.688	-17.779	-10.674	-17.800	-17.993
Industry	-32.893	-11.510	-4.089	-14.464	-21.290
Whole Economy	-32.904	-15.210	-4.292	-15.610	-19.431

Table 12. Effect of Carbon Taxes (US$22.2/ton CO₂) on Energy Demand and CO₂ Emission by 2020 (22 Year Progressive Ad Valorem Tax Approach)

(Unit: %)

	(1) Coal	(2) Oil	(3) Nature Gas	(4) Electricity	(5) CO₂
Agriculture	0.000	-21.975	0.000	-21.389	-23.018
Mining	-44.639	-24.348	-11.523	-10.690	-35.67
Coal Mining	–	–	–	–	–
Natural Gas	-100.000	-9.679	0.004	-11.868	-10.431
Manufacturing	-42.624	-15.332	-6.564	-20.215	-27.532
Food	-44.700	-20.576	-11.887	-21.260	-22.271
Beverage & Tobacco	-44.688	-20.559	-11.868	-21.243	-22.399
Textiles	-43.052	-14.222	-9.261	-19.401	-19.298
Clothes & Wearing Apparel	-43.554	-16.943	0.000	-20.185	-20.411
Leather & Leather Products	-44.901	-20.865	37.239	-21.557	-22.273
Wood & Bamboo Products	-36.994	-20.853	-12.194	-21.539	-22.3
Furniture Products	-37.084	-20.840	-12.180	-21.526	-22.257
Paper & Printing	-43.397	-18.705	-9.810	-19.404	-21.185
Chemical & Plastic	-100.000	-19.196	0.000	-19.182	-20.908
Rubber Products	-38.475	0.000	0.000	-20.515	-21.079
Oil Refinery	-30.798	0.137	16.860	-6.172	-29.541
Non-Metallic Mineral	-38.229	-11.592	36.445	-16.385	-27.898
Basic Metal	-63.411	-17.194	-26.604	-27.571	-62.162
Metal Products	-43.905	-19.434	-10.619	-20.127	-23.827
Machinery & Equipment	-44.015	-19.591	21.346	-20.456	-23.459
Elect. Mach. & Electronics	-44.543	-20.350	-11.636	-21.035	-21.791
Transport Equipment	-57.712	-39.265	-32.620	-39.788	-40.174
Miscellaneous	–	–	–	–	–
Water, Electricity & Gas	-37.011	-10.054	-0.523	-11.072	-33.89
Electricity	-29.248	0.465	11.367	-1.080	-28.195
Construction	-43.927	-19.466	0.000	-20.159	-35.913
Transportation & Comm.	-45.554	-21.782	0.000	-22.699	-24.3
Services	-46.832	-23.638	-15.284	-24.296	-24.488
Industry	-42.224	-15.242	-6.281	-19.816	-28.081
Whole Economy	-42.238	-20.132	-6.558	-21.344	-25.707

4.5 Comparison of Carbon Tax and Energy Tax

Effect on relative energy price

After carbon and energy taxes are levied, all energy prices are lower than that of coal. Imposing only a carbon tax will result in even lower energy prices relative to coal price than imposing an energy tax.

Comparison of the effect of carbon and energy taxes on the economy and CO_2 emission

It is difficult to use the same tax rate to compare the effects of carbon tax and energy tax because different types of energy have different tax rates. Therefore, the method of trial and error is used to estimate the same reduction rate of CO_2 emission for carbon tax and energy tax respectively. Then, the corresponding negative impacts on GDP deflator and economic growth are compared corresponding to two different kinds of tax.

Based on primary energy demand and CO_2 emission, the energy tax is calculated as NT\$2.19/LOE, corresponding with the Swedish carbon tax amount, US\$22.2/ton CO_2.

Assuming an ad valorem tax is imposed, by 2020, carbon tax and energy tax rates are the same as for 1999. Taking coal as an example, the carbon tax rate and the energy tax rate are 57.34% and 44.35%, respectively, in 1999 and 2020. The rates of energy tax and carbon tax are shown in Table 1 and Table 13, respectively.

Table 13. Comparison of Different Energy Taxes and Energy Prices in 1998

(Unit: NT\$ /LOE)

	Coal	Gasoline	Diesel	Fuel	LPG	Natural Gas	Electricity
Price in 1998	4.51	19.15	12.07	3.77	7.14	7.34	19.37
	(100.00)	(100.00)	(100.00)	(100.00)	(100.00)	(100.00)	(100.00)
Converted From Dutch Carbon Tax Amount[1] (NT\$0.16/LOE)	0.157	0.157	0.157	0.157	0.157	0.157	0.157
	(3.488)	(0.821)	(1.303)	(4.172)	(2.203)	(2.143)	(0.812)
Converted From Finnish Carbon Tax Amount[1] (NT\$0.28/ LOE)	0.276	0.276	0.276	0.276	0.276	0.276	0.276
	(6.119)	(1.441)	(2.286)	(7.320)	(3.865)	(3.760)	(1.425)
Converted From Danish Carbon Tax Amount[1] (NT\$1.05/ LOE)	1.045	1.045	1.045	1.045	1.045	1.045	1.045
	(23.168)	(5.456)	(8.657)	(27.716)	(14.634)	(14.235)	(5.394)
Converted From Swedish Carbon Tax Amount[1] (NT\$1.56/ LOE)	1.56	1.56	1.56	1.56	1.56	1.56	1.56
	(34.565)	(8.140)	(12.915)	(41.350)	(21.833)	(21.238)	(8.048)

Note: The conversion factor from carbon tax rate to energy tax rate is based on Taiwan energy usage and CO_2 emission in 1998. LOE stands for liter oil equivalent.

Table 14. Comparison of the Impact of Carbon Tax & Energy Tax on Price, CO_2 Emission and Output Growth by Sector in 1999 (One Step Approach)

(Unit: %)

	Output-price		Output		CO_2-Reduction	
	Carbon Tax US$ 22.2 /ton-CO_2	Energy Tax NT 2.19/LOE	Carbon Tax US$ 22.2 /ton-CO_2	Energy Tax NT 2.19/LOE	Carbon Tax US$ 22.2 /ton-CO_2	Energy Tax NT 2.19/LOE
Agriculture	3.237	3.407	-1.166	-1.224	-21.855	-22.999
Mining	4.503	4.702	-4.197	-4.335	-37.617	-36.634
Coal Mining	97.615	84.420	-0.857	-0.959	–	–
Natural Gas	10.139	13.639	-1.917	-2.479	-12.003	-11.977
Manufacturing	8.792	9.164	-1.566	-1.609	-27.931	-27.602
Food	5.544	5.846	-0.345	-0.381	-21.198	-22.677
Beverage & Tobacco	5.563	5.867	-0.616	-0.657	-20.743	-21.803
Textiles	8.867	9.490	-0.722	-0.812	-18.265	-20.132
Clothes & Wearing Apparel	8.238	8.791	-0.357	-0.387	-19.346	-20.762
Leather & Leather Products	3.803	4.032	-0.374	-0.409	-20.455	-22.474
Wood & Bamboo Products	2.826	3.015	-0.505	-0.569	-22.344	-24.177
Furniture Products	2.859	3.051	-0.500	-0.563	-22.369	-24.202
Paper & Printing	7.179	7.553	-1.017	-1.142	-21.371	-23.023
Chemical & Plastic	6.465	6.986	-1.862	-1.987	-23.249	-24.202
Rubber Products	5.316	5.647	-0.649	-0.711	-20.818	-22.370
Oil Refinery	28.707	29.793	-8.768	-9.084	-10.179	-10.181
Non-Metallic Mineral	19.523	19.416	-3.321	-3.345	-27.023	-25.640
Basic Metal	8.667	9.059	-2.207	-2.354	-83.013	-82.149
Metal Products	5.773	6.201	-0.525	-0.572	-23.567	-24.559
Machinery & Equipment	5.628	6.000	-0.451	-0.484	-22.709	-23.680
Elect. Mach. & Electronics	5.282	5.607	-0.214	-0.243	-21.264	-23.121
Transport Equipment	5.366	5.721	-0.242	-0.267	-21.522	-22.972
Miscellaneous	7.424	7.676	-6.909	-7.714	–	–
Water, Electricity & Gas	24.754	25.942	-11.291	-11.328	-35.733	-34.501
Electricity	34.221	38.585	-8.928	-8.850	-23.208	-18.885
Construction	5.257	5.574	-0.717	-0.700	-36.230	-34.099
Transportation & Comm.	3.572	3.780	-2.004	-2.086	-21.939	-22.719
Services	1.866	1.921	-0.224	-0.247	-22.747	-24.853
Industry	9.384	9.802	-2.160	-2.198	-28.546	-28.168
Whole Economy	4.505	4.694	-1.010	-1.043	-25.802	-25.802

Note: LOE stands for liter oil equivalent.

Table 15. Comparison of the Effect of Carbon Tax & Energy Tax on Price, CO_2 Emission and Output Growth by 2020 (22 year Progressive Ad Valorem Approach)

(Unit: %)

	Output-price		Output		CO_2-Reduction	
	Carbon Tax US$ 22.2 /ton-CO_2	Energy Tax NT 2.19/LOE	Carbon Tax US$ 22.2 /ton-CO_2	Energy Tax NT 2.19/LOE	Carbon Tax US$ 22.2 /ton-CO_2	Energy Tax NT 2.19/LOE
Agriculture	1.324	1.245	-1.304	-1.269	-23.018	-22.368
Mining	4.240	4.023	-3.694	-3.474	-35.67	-31.720
Coal Mining	85.200	67.320	-0.619	-0.635	–	–
Natural Gas	16.231	20.017	-3.575	-4.204	-10.431	-8.986
Manufacturing	6.261	5.942	-1.268	-1.197	-27.532	-24.903
Food	2.416	2.294	-0.320	-0.342	-22.271	-22.077
Beverage & Tobacco	2.437	2.315	-0.629	-0.629	-22.399	-21.729
Textiles	5.468	5.313	-0.882	-0.929	-19.298	-19.592
Clothes & Wearing Apparel	4.878	4.722	-0.569	-0.573	-20.411	-20.133
Leather & Leather Products	2.646	2.538	-0.478	-0.530	-22.273	-22.403
Wood & Bamboo Products	1.905	1.846	-0.972	-1.001	-22.3	-22.067
Furniture Products	1.932	1.871	-0.942	-0.970	-22.257	-22.025
Paper & Printing	4.829	4.607	-0.761	-0.802	-21.185	-21.001
Chemical & Plastic	4.460	4.395	-1.349	-1.322	-20.908	-20.234
Rubber Products	3.418	3.286	-0.321	-0.369	-21.079	-21.280
Oil Refinery	28.948	27.315	-7.101	-6.704	-29.541	-7.440
Non-Metallic Mineral	14.399	12.992	-2.495	-2.282	-27.898	-23.753
Basic Metal	6.959	6.531	-8.756	-7.873	-62.162	-54.154
Metal Products	3.888	3.800	-0.456	-0.459	-23.827	-22.681
Machinery & Equipment	3.641	3.533	-0.609	-0.597	-23.459	-22.298
Elect. Mach. & Electronics	3.048	2.919	-0.360	-0.380	-21.791	-21.699
Transport Equipment	3.360	3.244	-0.020	-0.020	-40.174	-40.356
Miscellaneous	6.250	5.849	-6.030	-6.151	–	–
Water, Electricity & Gas	22.136	21.173	-8.783	-7.902	-33.89	-28.894
Electricity	30.067	31.083	-6.936	-6.162	-28.195	-17.285
Construction	3.265	3.130	-1.032	-0.920	-35.913	-31.115
Transportation & Comm.	0.867	0.811	-2.398	-2.288	-24.3	-22.992
Services	–	–	-0.251	-0.257	-24.488	-51.696
Industry	6.945	6.607	-1.784	-1.651	-28.081	-25.289
Whole Economy	2.392	2.274	-0.932	-0.883	-25.707	-25.707

Note: LOE stands for liter oil equivalent.

The conclusions are as follows:

(1)   The One Step Approach: To achieve the same goal of reducing CO_2 emission by 25.8%, the implementation of a carbon tax will result in an increase in the GDP deflator by 4.51% and a decrease in GDP by 1.01%. In contrast, the implementation of an energy tax will lead to an increase in the GDP deflator by 4.69 % and a decrease in GDP by 1.04 %. Consequently, the carbon tax is slightly better than the energy tax, owing to its smaller impact on price level and GDP growth under the same CO_2 emission reduction goal (Table 14).

(2)   The progressive Ad Valorem Approach: Adopting a progressive ad valorem approach (tax rate increases progressively year by year for 22 years), with the same reduction goal of 25.27% in total CO_2 emission, by 2020, the carbon tax on coal, for example, is 57.34 %, while the energy tax rate is 44.35 %. Implementing an energy tax will increase the GDP deflator by 2.274% and decrease GDP by 0.883%. Conversely, implementing a carbon tax will increase the GDP deflator by 2.392% and decrease economic growth by 0.932%. The negative effects of the energy tax are smaller than for a carbon tax, making it better than the carbon tax when using a progressive ad valorem approach (refer to Table 15). The result of the progressive approach on carbon tax and energy tax differs from that of the one step approach could be attributed to the BAU (business as usual) assumption in our base projection.

(3)   Since either a carbon or energy tax in a progressive ad valorem approach can effectively reduce carbon emission while minimizing its negative impact on price level and economic growth, the progressive ad valorem approach is strongly recommended.

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