A Monte-Carlo Dynamic CGE Model for the Impact Analysis of Thailand's Carbon Tax Policies

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Abstract: In the past 30 years, the static CGE model has been widely used in the analysis of environmental economics. In the case of Thailand, there are many studies which use static CGE models to explore economy-wide impacts of imposing policies on CO_2 emission. However, the static model has a limitation in its one-period comparative static feature. Hence, in this study, the recursive dynamic process has been included in the model to extend its capability of simulating the growth path of Thai economy and sectoral adjustment in medium-run and long-run. In addition to the dynamic feature, the Monte-Carlo technique is implemented by running the dynamic model with various sets of parameters randomly generated from given distribution properties. This enhanced capability of performing both stochastic and dynamic simulations expands the dimension of impact analysis of carbon tax policies, especially toward the multi-period effects and their stochastic properties over time. This new technique will be the alternative model for studying the robustness of impacts of carbon-tax policies on Thai economy.

1. Introduction

Since its first formulation and implementation of National Economic and Social Development Plan in 1950s, Thailand has been continuously transformed its economic structure from the agricultural-based nation to the export-led economy. This transformation led to the expansion of national GDP at very high growth rates during 1985-1997 (the average growth rate was 8.6%). Also after the Asian Financial Crisis in 1997-1999, Thai economy recovered and has been growing at the GDP growth rate of 5.7% (as shown on Figure 1). Certainly, this continuous expansion causes the growing demand for energy that mainly serves manufacturing and transportation activity, and it subsequently influences the increasing emission of CO_2. As shown on Figure 2 and 3, the trend of per capita CO_2 emission and the average per capita CO_2 emission of Thailand has been following the national growth path, and expected to continuously increase.

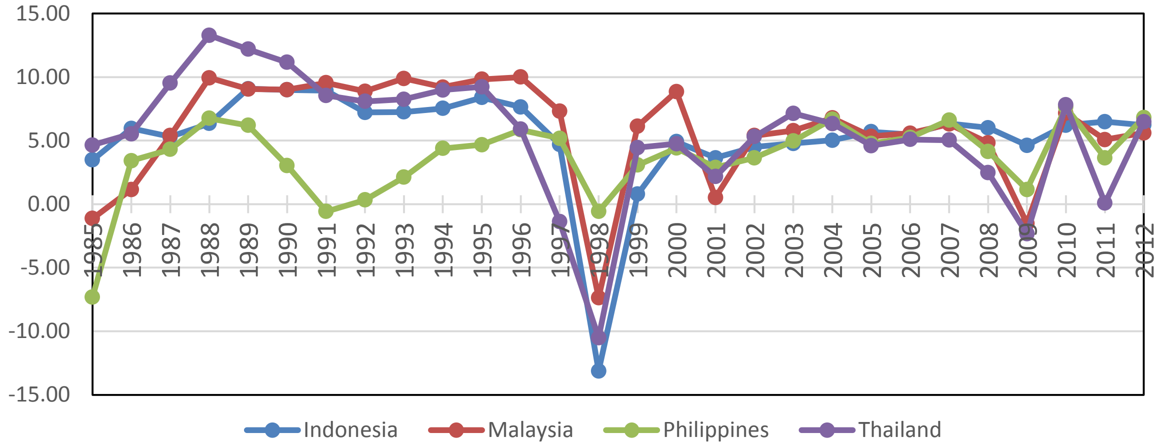

Figure 1. Annual percentage growth of real GDP of selected Asian counties [1]).

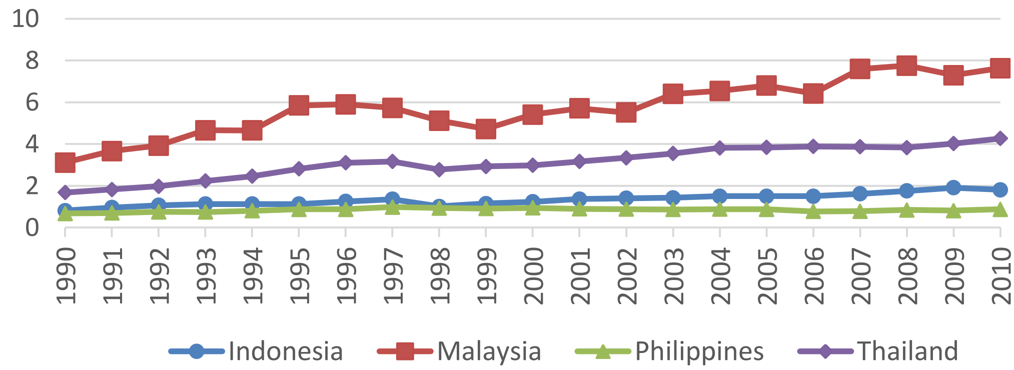

Figure 2. Trend of Per Capita CO_2 emission (Metric Tons) of selected Asian countries [2].

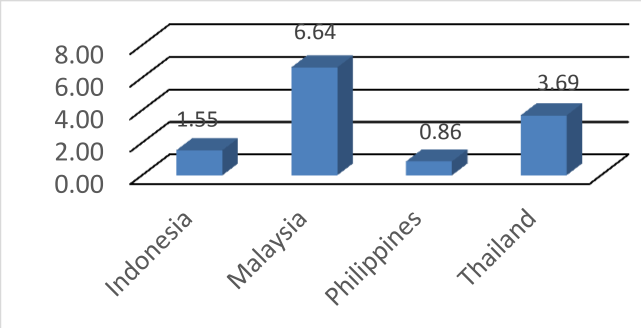

Figure 3. Average Per Capita CO2 emission (Metric Tons) of selected Asian countries in 2010 [2].

Regarding the national policy on Green House Gas (GHG) emission, Thailand has been conducting the voluntary GHG mitigation under framework called "Nationally Appropriate Mitigation Actions (NAMAs)" since its collaboration in the 15th Conference of the Parties (COPS 15th) and the 5th Conference of the Member Parties to the Kyoto Protocol (CMP5). Under this policy framework, the baseline projection of the nationwide GHGs emission was developed and the target of 60Mt-CO_2 reduction in 2020 was introduced. To support this emission reduction policy and propose additional policy measures, there are many studies utilizing CGE models, but there is still a concern regarding the stability of coefficients' values of the model. Therefore, this paper aims at incorporating the Monte-Carlo simulation technique into the recursive dynamic CGE model of Thailand. By solving models with various combinations of coefficients and exogenous variables randomly produced under a given statistical distribution, the range of all possible simulation results is generated. This technique broadens the dimension of CGE model from comparative static to the stochastic analysis, enabling the verification of the stability of simulation results in response to the stochastic shocks, especially on economy-wide impacts of GHGs reduction.

The structure of this paper is outlined as follows. The second section introduces the review of literatures related to the CGE model and GHGs emission policy. The third part describes the model's main structure and the Monte-Carlo simulation. The results of static and Monte-Carlo simulations are discussed in the fourth section. The last part concludes the results and suggests the guidance for future development on this modeling technique.

2. Literature review

Scarf (1967), Shoven and Whalley (1973, 1984) are among the first group of CGE developers introducing mathematical and programming techniques of applied general equilibrium modeling [3-5]. With the first oil shock in early 1970s, the CGE model gained its popularity due to its economy-wide structure allowing users to trace all adjustment of prices and quantities. Goulder (1982) and Borgess and Goulder (1984) were among the first who used CGE models to study economy-wide impacts of energy policies and also Berman(1991) was the first applying CGE to the field of environmental economics [6-8]. With the rising concerns on climate change, the CGE model has become one of the main tools in analyzing impacts of GHGs emission policies. For the cost analysis of reducing CO_2 emission, Whalley and Wiggle (1991a, 1991b), Manne and Richels (1991, 1994), Jorgenson and Wilcoxen (1993a, 1993b), and Bergman (1991) are among the first group of studies applying CGE model in this field [8-14]. In the case of country-specific analysis, Xie and Saltzman (2000) developed the CGE model to study the relationship between production and pollution in China [15]. Roson (2003) used CGE to examine impacts of environmental tax in Italy [16]. Labandeira et al. (1999, 2004, 2006) used CGE model to analyze impacts from imposing tax on energy goods of Spain and found that the effect on welfare of consumers is moderate [17-19]. In addition, these work shows that the reallocation of revenue from this energy tax to the appropriate sectors is the effective solution to minimize the welfare loss. Dessus and O' Connor (2003) applied the CGE to the case of Chile and found that health benefits gaining from the reduction of CO_2 emission would offset the welfare loss [20]. Also O'Ryan et al. (2003, 2005) applied the CGE model to the case of Chilean economy, and found that the GHGs reduction policies can influence some negative social impacts [21-22].

In the case of Southeast Asian countries, Corong (2008) used the CGE model to show that in the case of the Philippines, the carbon tax can be progressively collected with the reduction in sales tax [23]. Yusuf and Resosudarmo (2007, 2008) applied the CGE model to the case of Indonesia, and obtained the similar simulation outcomes to that of Corong (2008), suggesting that to minimize the welfare loss, the carbon tax should be simultaneously imposed with the lowered sales tax [23-25]. Al-Amin et al. (2008) used the CGE model to the case of Malaysia and showed the computational result which optimizes the trade-off between CO_2 reduction and economic growth [26].

For Thailand, there are some studies using the CGE model to exploring impacts of reducing GHGs emission. Timilsina (2007) applied CGE model to explore the minimized welfare loss from the reallocation of the collected carbon tax [27]. Thepkhuna et al. (2011) used AIM/CGE model to projection the basecase of CO_2 and exhibited how policy instruments can induce the GHGs emission reduction to meet the targeted level [28]. Although these studies can show the nationwide impacts of imposing carbon tax, there are still some concerns regarding the robustness of simulation results. Hence, this study applies the Monte-Carlo technique to the standard CGE to conduct the sensitivity analysis on CGE's simulation.

3. Model structure and Monte-Carlo simulation

The CGE model structure follows the recursive dynamic CGE model developed by Decaluwé et al. (2013)[1], which enables adjustment of price and quantity of most goods and input factors [29]. In this study, the main assumptions of the CGE model include[2]:

- Producers have the main purpose to maximize profit and their production behaviors are under the constant-return-to-scale condition.
- Consumers aim at maximizing under the budget constraints, and deciding on consuming a combination of domestic and imported goods.
- All markets of goods and services are in equilibrium and prices are equilibrating variables.
- There is non-linear behavior in the frictional substitution mechanism between domestic and export products and the similar frictional mechanism of substitution between domestic and imported goods.
- The exchange rate, governmental consumption, and tax rates are specified as exogenous variables representing policy instruments.
- Institutions in the model include five groups of households, the government, the aggregate representative of corporations, and the rest of the world.
- The Social Accounting Matrix (SAM) of Thailand in 2010 is the main source of data, including 40 production activities, 49 commodities, the aggregate household, the government, and the rest of the world.

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[1] http://www.pep-net.org/programs/mpia/pep-standard-cge-models/pep-1-t-single-country-recursive-dynamic-version/

[2] The full mathematical details of this model are available upon request.

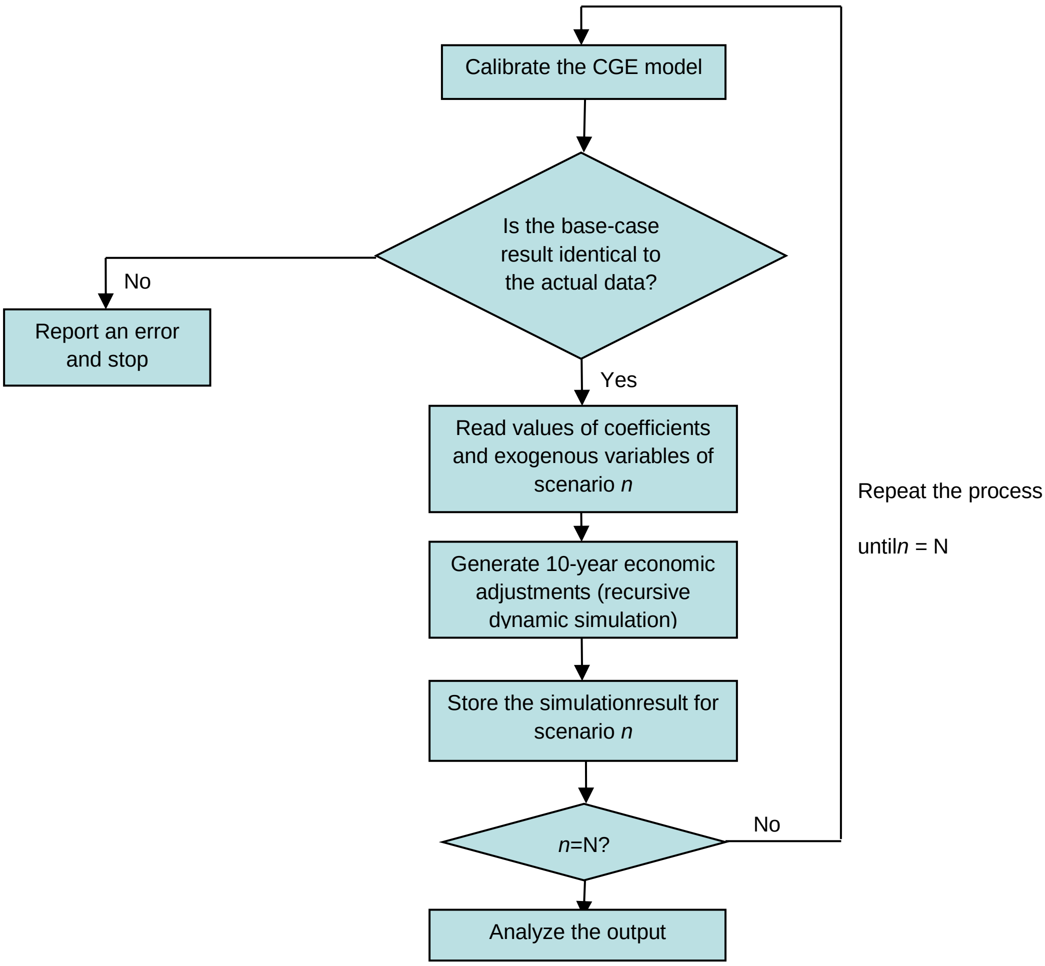

Figure 4. Flow chart of applying the Monte-Carlo simulation to the recursive dynamic CGE model.

The first set of simulations uses the CGE model to examine the economy-wide impact when three rates of carbon taxes are imposed. The model generates the possible scenarios of Thai economy in 10-year period (i.e. during 2010-2019). The first simulation generates the Business As Usual (BAU) scenario, estimating the usual growth path and expected incrementing carbon emission in 10-year period. The later three simulations explore the dynamic economy-wide responses to rates of 227.75 baht, 455.49 baht and 683.23 baht per ton of CO_2[3].In each simulation, the tax is constant throughout the 10-year period because the main objective is to examine how Thai economy dynamically reacts to each level of tax. So, the variation of tax rate over time is excluded. In this model, the amount of emitted CO_2 is computed by based on the usage of fossil fuels in each production activity. Specifically, for each production sector, its demands for fossil fuel as intermediate inputs are multiplied by their corresponding emission factors.

In addition to conducting static analysis, the CGE model's capability is enhanced to perform a Monte-Carlo simulation. This new feature allows the model to repeatedly simulate the recursive dynamic model with values of parameters and exogenous variables randomly generated under given stochastic properties. Technically speaking, the recursive dynamic CGE model is extended its capability to perform the loop of calculation as shown in Figure 1. In the first step, the model is initialized by assigning initial values to all parameters and exogenous variables. In the second procedure, the model runs a base case simulation. If all values of endogenous variables generated in the first run are identical to those of the actual base case, the model is allowed to perform a loop of repeating computation, with the total number of N iterations. Specifically, in each n^{th} iteration, the process starts with assigning a new set of values of parameters and exogenous variables. Then the model generates the outcome which is a scenario of the economy's 10-year growth path under this given condition. After finishing the computation of the n^{th} iteration, the forecasted values of macro variables of Thai economy are stored and the model iterates the calculation loop by fetching the next set of values of parameters and exogenous variables representing the alternative given condition for Thai economy. This computational loop repeats until it reaches the last set of parameters values and exogenous variables. In the final process, the property statistical distribution of each endogenous variable is calculated by using values obtained from all scenarios. Because the function of generating a random value under a specific distribution property does not exist in the GAMS package, the set of stochastic shocks (the set of values of parameters and exogenous variables) is computed outside GAMS[4] before running the Monte-Carlo simulation of CGE on GAMS.

[3] The carbon-tax rate of 445.49 baht per ton is based on the average value of European countries (www.investing.com/commodities/carbon-emissions-historical-data). The rate of 227.75 baht and 683.23 baht are arbitrarily assigned as the 50% and 150% of level of the Euro's average (445.49 baht), respectively. Both rates represent the possible variation of the tax rate to be imposed.

[4] In this study, the selected parameters and exogenous variables were randomized under the specified distribution properties by using Excel.

4. Simulation results

4.1 Verification of results generated in the Business as Usual (BAU) scenario

In this study, there are six key exogenous variables that substantially determine the economy's annual growth. These exogenous variables are:

- An annual growth of total population
- An annual growth of labor productivity
- An annual growth of capital productivity
- An annual growth of total government expenditure
- An annual growth of total investment
- An annual growth of Thailand's total export

To replicate the long-term expansion of Thai economy, the 12-year average growth rates (2001-2012) of above exogenous variables are main inputs for the recursive dynamic CGE model. The results of simulating10-year growth path are shown on Table 1, exhibiting the annual growth of main macro variables. By comparing with the actual growth during 2001-2012, the average values of most key variables generated by this CGE model are close to those actual ones, confirming that the 10-year growth path simulated in the BAU case is within the acceptable range.

4.2 Static simulations of imposing three rates of carbon tax

To examine how Thai economy responds to the carbon tax, the recursive dynamic CGE with configuration as stated in 4.1 is used with the imposition of carbon tax. Specifically, there are three scenarios generated by imposing the low, medium and high rates of carbon tax, respectively. The medium rate (445.49 baht per ton of CO_2) is the average value of carbon tax imposed in European countries in 2012. In addition, two scenarios representing the cases of imposing the low and the high rates of 227.75 baht and 683.23 baht are simulated. It is noted that the rate of 227.75 baht and 683.23 baht represent the possible variation of the imposed tax which can be either a 50% lower or 50% higher that of European's average. In this model, the carbon tax is directly imposed on the producer of each sector, implying that it is a responsibility of each production sector to pay the carbon tax based on its CO_2 emission.

Simulation results shown in Figures 5 and 6 indicate that imposing the carbon tax on the producers can immediately cause the responses of contracting aggregate supply, based on the conventional economic theory assuming the behavior of producers to maximize their profits under the given costs. With this action, the aggregate output, i.e. real GDP, will be lowered. Also, due to the increased production costs, the carbon tax triggers the producers to pass their higher cost burden through the higher retail price, resulting in the economy-wide raising price level (i.e. inflation). Since the employment decision directly depends upon the expansion or contraction of production, the outcome of nationwide lowered manufacturing and related activities subsequently induces the lower employment (Figure 8). This adjustment also leads to a lower household's income (Figure 10) and decreasing consumption expenditure (Figure 7). However, this carbon tax regime gains the government's revenue (Figure 9) and reduces the total carbon emission (Figure 11). As exhibited on these figures, the higher tax rate will lead to a greater degree of economic contraction as indicated by the lower level of real GDP, employment, household's income and consumption. Also the higher rate of carbon tax leads to a higher inflation, but it gains the government's revenue and lower the CO_2 emission. These simulation results are similar to main findings of many studies as summarized in Cuervo and Gandhi (1998) [30]. Also these simulation outcomes are analogous to the recent findings in the case of Australian economy and that of U.S., where the carbon tax can induce the contraction of production and the higher inflation [31-32]. In addition, Goulder and Hafstead (2013) emphasize on recycling the collected carbon tax as a constructive measure to counter the nationwide negative impacts [32].

Table 1. Annual growth rates of key macro indicators generated by the BAU scenario of the recursive dynamic CGE model.

	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Average
Real GDP	5.56%	5.60%	5.65%	5.71%	5.76%	5.82%	5.88%	5.94%	6.00%	5.77%
Inflation	1.77%	1.61%	1.46%	1.32%	1.19%	1.06%	0.94%	0.83%	0.72%	1.21%
Total private consumption	5.52%	5.55%	5.59%	5.64%	5.69%	5.75%	5.80%	5.86%	5.92%	5.70%
Total employment	6.57%	6.56%	6.55%	6.54%	6.53%	6.52%	6.51%	6.50%	6.50%	6.53%
Total government revenue	5.46%	5.53%	5.59%	5.67%	5.74%	5.81%	5.88%	5.95%	6.02%	5.74%
Total household's income	5.52%	5.55%	5.59%	5.64%	5.69%	5.75%	5.80%	5.86%	5.92%	5.70%
Total CO_2 emission	2.55%	2.77%	3.00%	3.22%	3.45%	3.67%	3.90%	4.11%	4.33%	3.45%

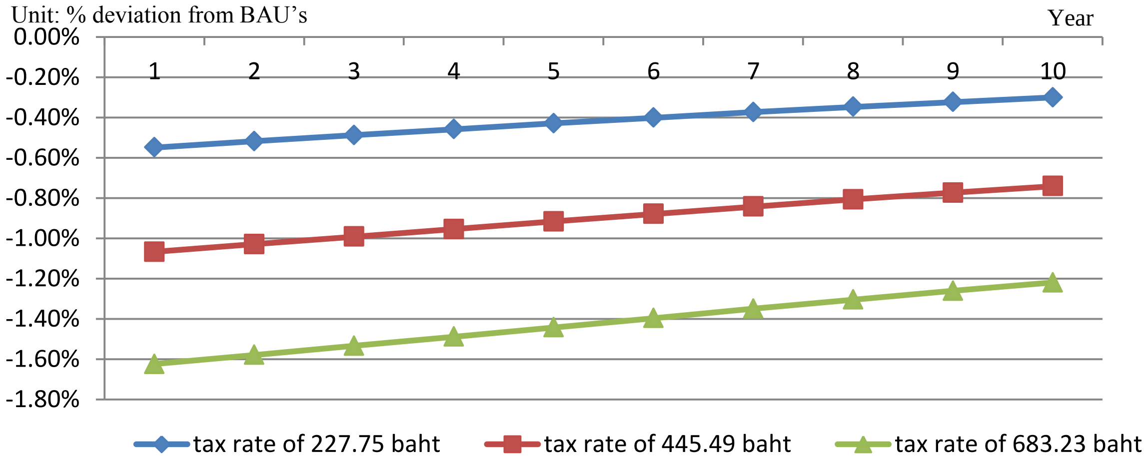

Figure 5. Responses of real GDP to three rates of carbon tax.

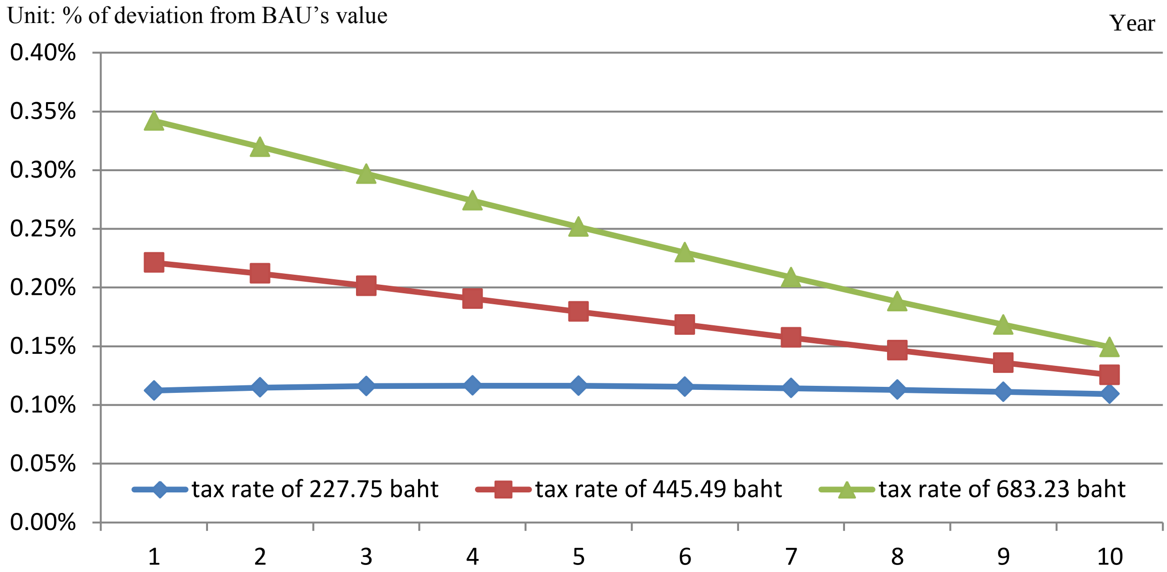

Figure 6. Responses of inflation to three rates of carbon tax.

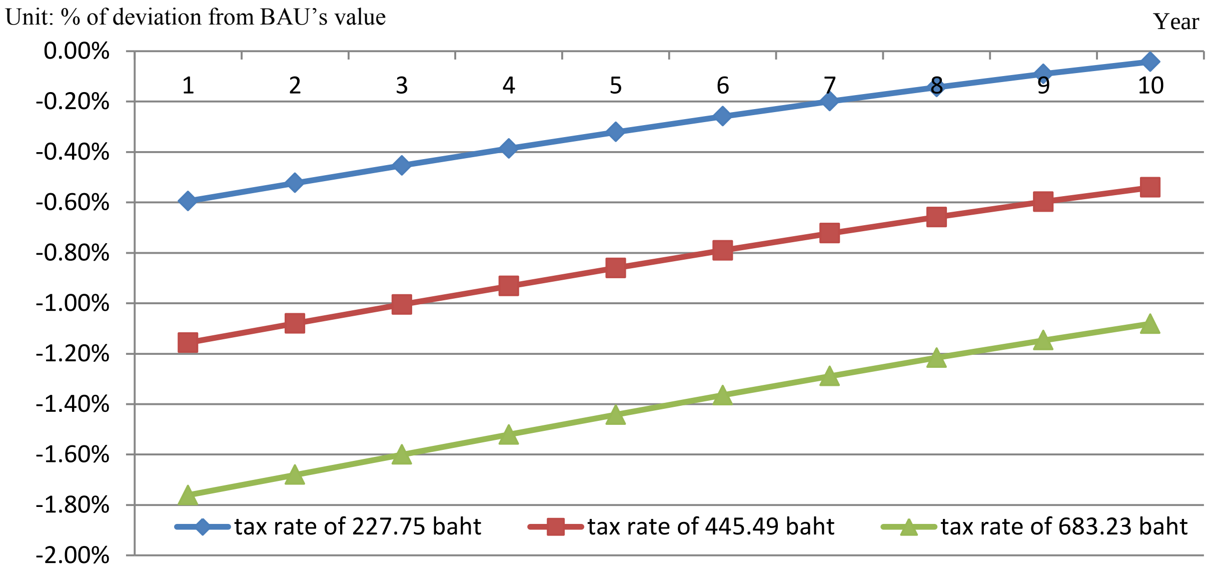

Figure 7. Responses of total private consumption to three rates of carbon tax.

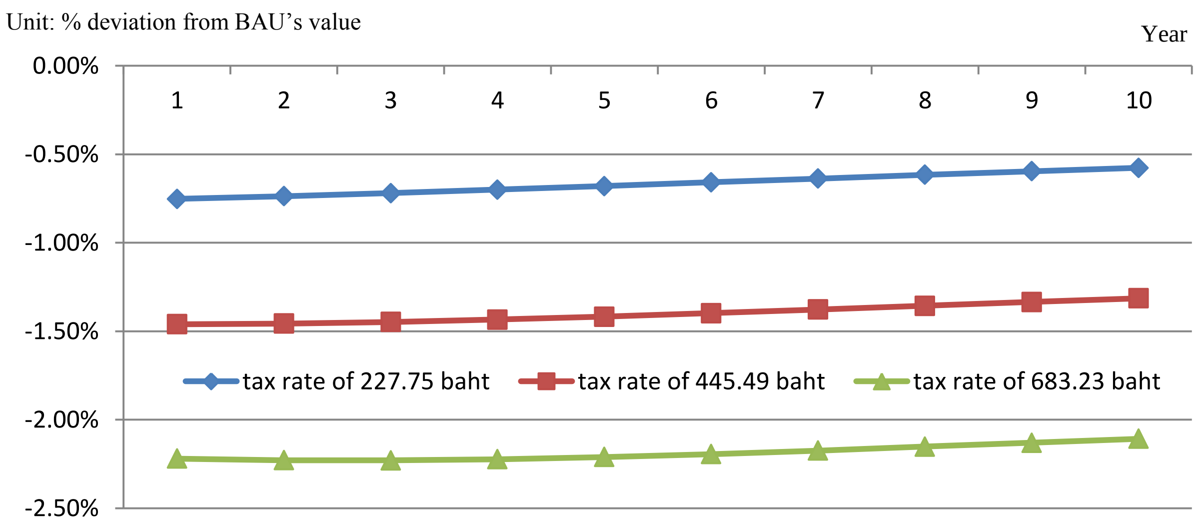

Figure 8. Responses of total employment to three rates of carbon tax.

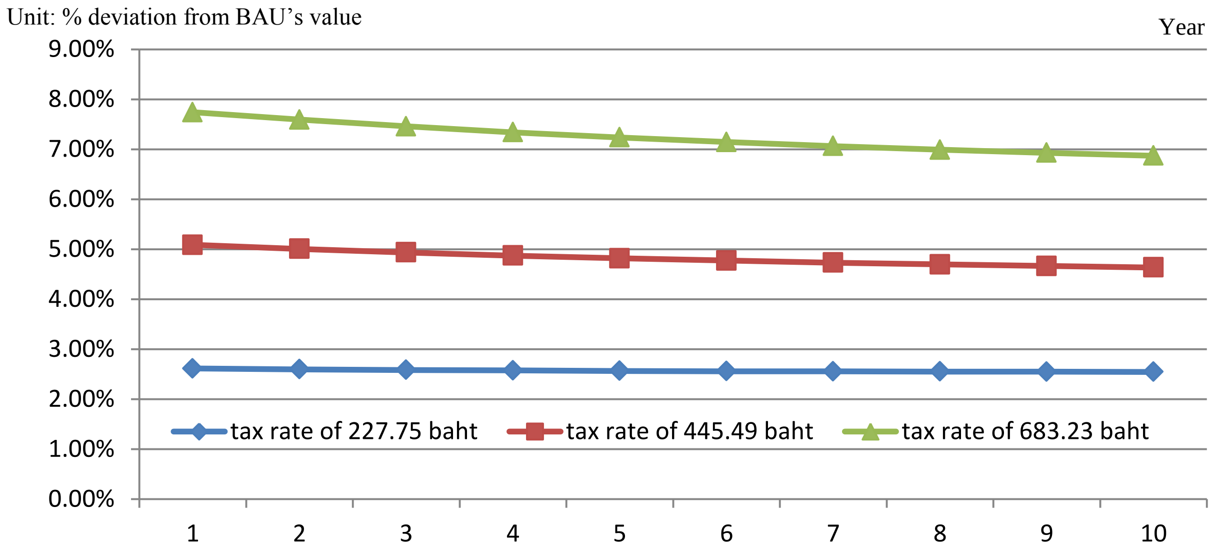

Figure 9. Responses of total government revenue to three rates of carbon tax.

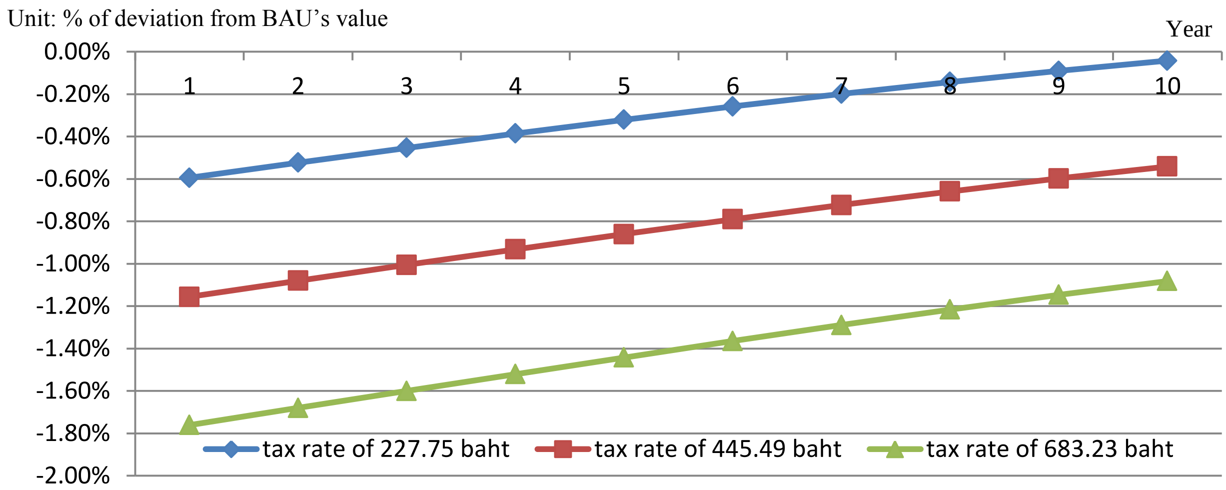

Figure 10. Responses of total household's income to three rates of carbon tax.

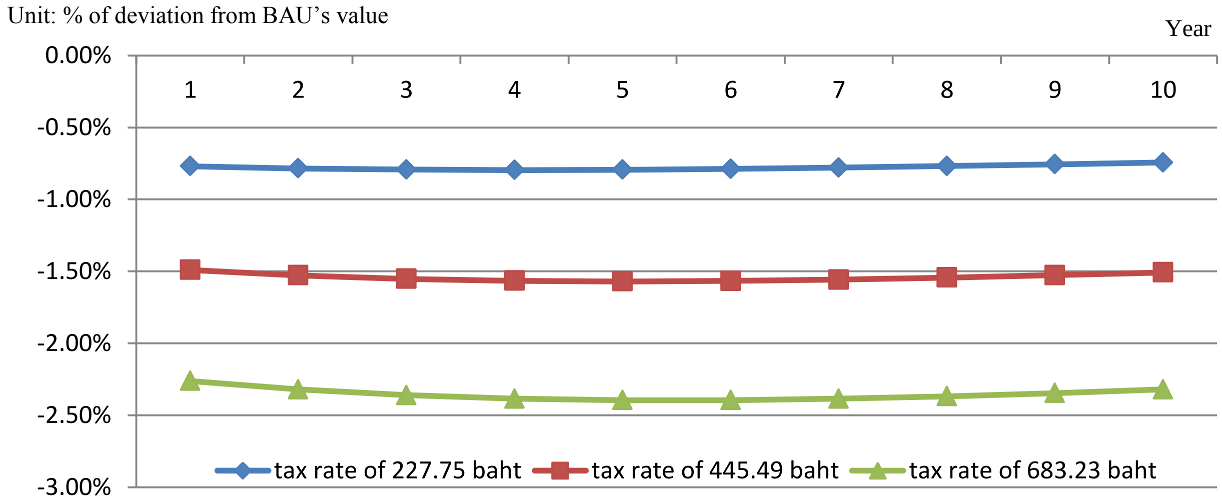

Figure 11. Responses of total CO_2 emission to three rates of carbon tax.

4.3 Monte-Carlo simulations of imposing three rates of carbon tax

To extend the dimension of analysis, the Monte-Carlo simulation has been conducted to examine the distribution property of generated results. Since results obtained from CGE modeling might be sensitive to the variation of exogenous variables and value of coefficients, the Monte-Carlo simulation is applied to the recursive dynamic model generating results shown in section 4.2. Specifically, the model is repeatedly simulated with randomized values of six key exogenous variables and two key coefficients governing elasticity of substitution in the nested structure of production[5], which are:

- An annual growth of total population
- An annual growth of labor productivity
- An annual growth of capital productivity
- An annual growth of total government expenditure
- An annual growth of total investment
- An annual growth of Thailand's total export
- Elasticity coefficient governing substitution between labor and capital in the production function
- Elasticity coefficient governing substitution between intermediate inputs and value-added components

Figures 12–18 show results of key variables obtained from Monte-Carlo simulation. For all variables, their values of standard deviation increase with longer time period of simulation. This pattern is caused by cumulative effects from variation of each simulation period. Interestingly these Monte-Carlo results indicate that in addition to the imposed carbon tax, volatility of those exogenous variables and elasticity coefficients can substantially affect the economy-wide adjustments, and final outcomes in the10th year may significant different from the results generated by the static simulation exhibited in section 4.2.

To compare the degree of variation, Table 2 exhibits values of Coefficient of Variation (i.e. the ratio of standard deviation per mean) of key variables. It is shown that the total employment has the highest value, while the government's revenue has the second largest value. This indicates that both variables are the most volatile compared to others. Also values of Coefficient of Variation of real GDP, total consumption and household's income are very alike, showing the high degree of sensitivity to the given stochastic shocks as well. The total emission and inflation have the lowest values of Coefficient of Variation, suggesting that both are less sensitive to the fluctuation of key exogenous variables.

Interestingly, the increasing ranges of maximum and minimum of simulation outputs in the later years, as exhibited on Figures 12-18, indicate that the degree of variation is greater when the time horizon expands. These results are caused by the cumulative effects of randomly selected values of parameters and exogenous variables that incur the continuous fluctuations in the economy. With the greater gap between the maximum and minimum values of simulated outputs in long run, it is very important for policy makers, when implementing the carbon tax regime, to continuously monitor and evaluate the conditions of the production activities and related factors because the ultimate impacts on the economy may be significantly deviated from the target. Hence, the revision of the tax rate and other characteristics of the imposed regime should be conducted every 3-5 years in order to update the policy that would be appropriate to the changing situations.

[5]The distribution property of these stochastic shocks is obtained from their historical distribution during 2001- 2012.

Table 2. Coefficient of Variation of key economic indicators.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Real GDP	0.50%	1.85%	3.66%	5.48%	7.32%	9.17%	11.03%	12.90%	14.79%	16.69%
Inflation	0.43%	0.87%	1.46%	2.01%	2.50%	2.92%	3.27%	3.57%	3.81%	3.99%
Total Consumption	0.53%	1.85%	3.63%	5.44%	7.25%	9.07%	10.91%	12.76%	14.61%	16.48%
Total employment	2.42%	3.09%	4.68%	6.52%	8.45%	10.39%	12.33%	14.27%	16.19%	18.10%
Total government's revenue	2.24%	2.92%	4.29%	5.90%	7.61%	9.37%	11.18%	13.02%	14.89%	16.78%
Total household's income	0.53%	1.85%	3.63%	5.44%	7.25%	9.07%	10.91%	12.76%	14.61%	16.48%
Total CO_2emission	0.95%	1.13%	1.67%	2.43%	3.35%	4.41%	5.60%	6.90%	8.31%	9.84%

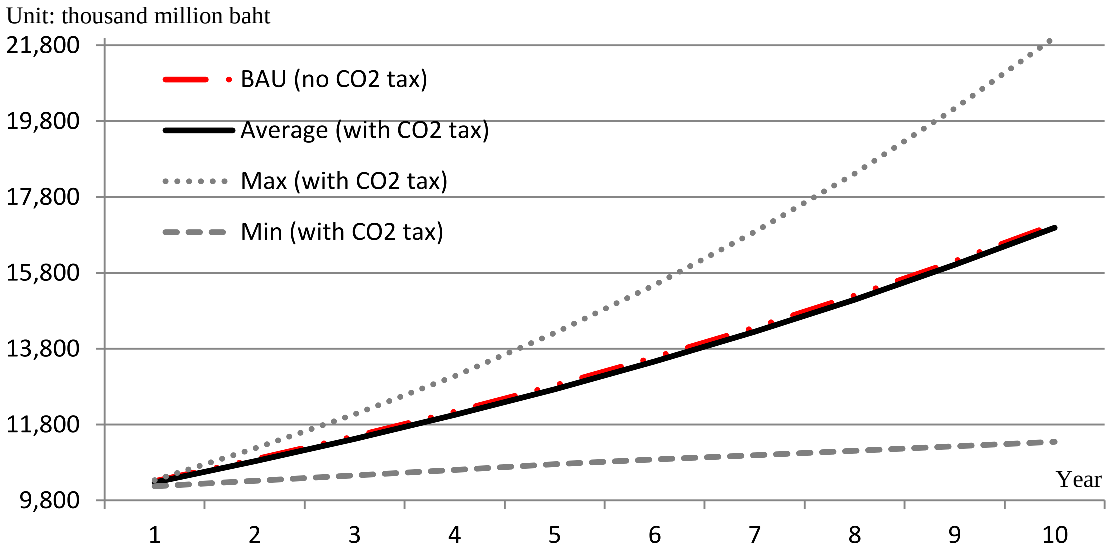

Figure 12. Statistical distribution of real GDP (with the tax rate of 445.49 baht) obtained from Monte-Carlo simulation.

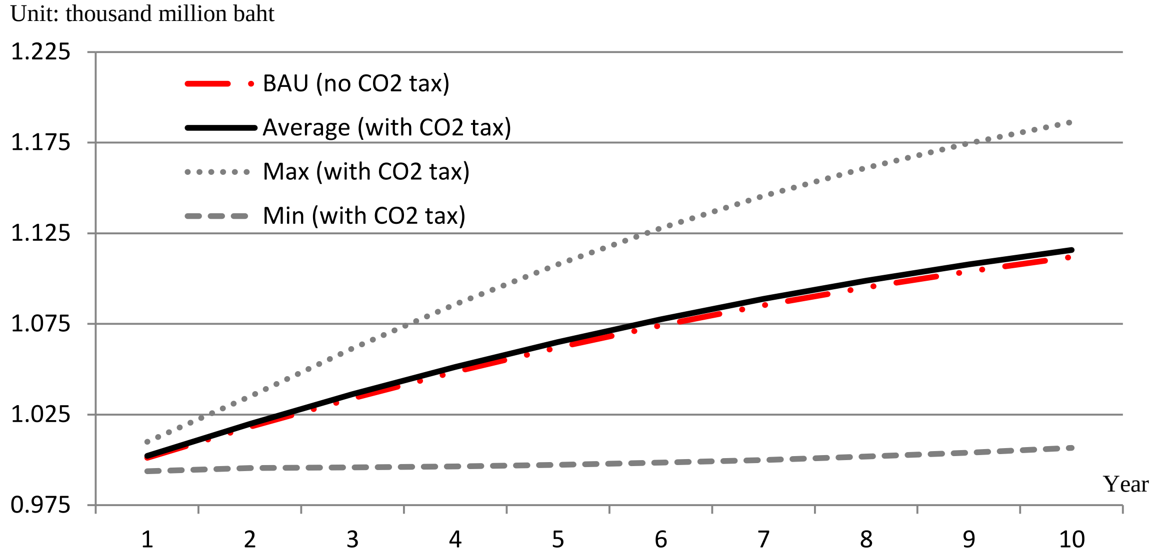

Figure 13. Statistical distribution of Consumer Price Index (with the tax rate of 445.49 baht) obtained from Monte-Carlo simulation.

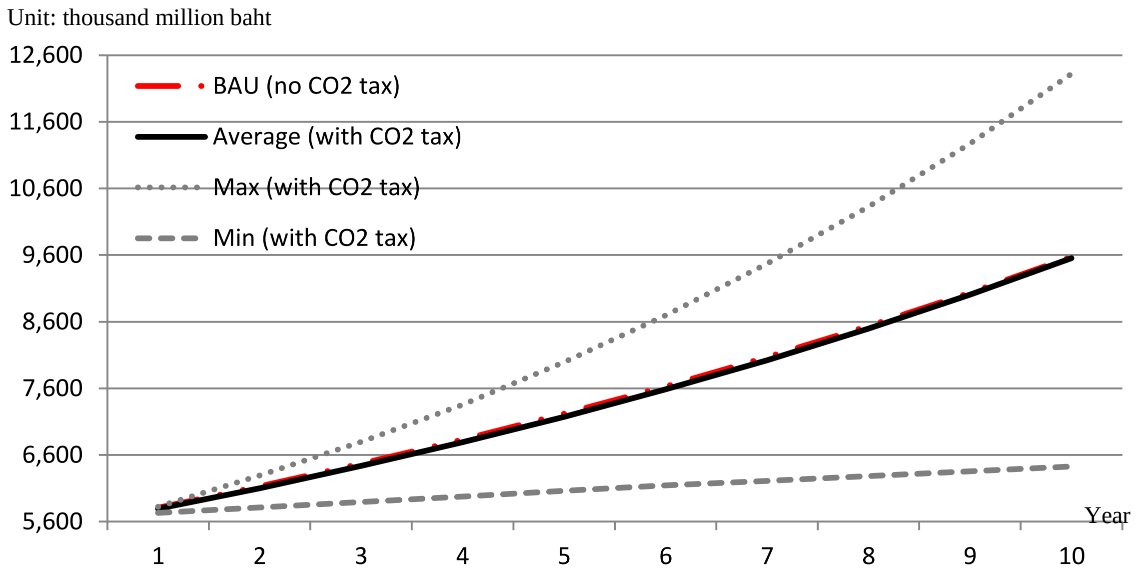

Figure 14. Statistical distribution of total consumption (with the tax rate of 445.49 baht) obtained from Monte-Carlo simulation.

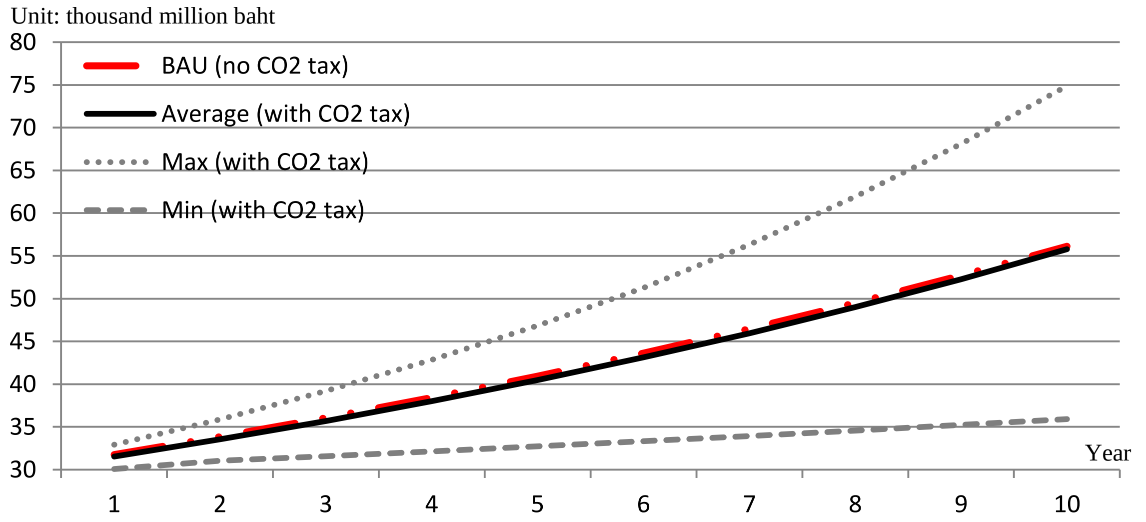

Figure 15. Statistical distribution of total employment (with the tax rate of 445.49 baht) obtained from Monte-Carlo simulation.

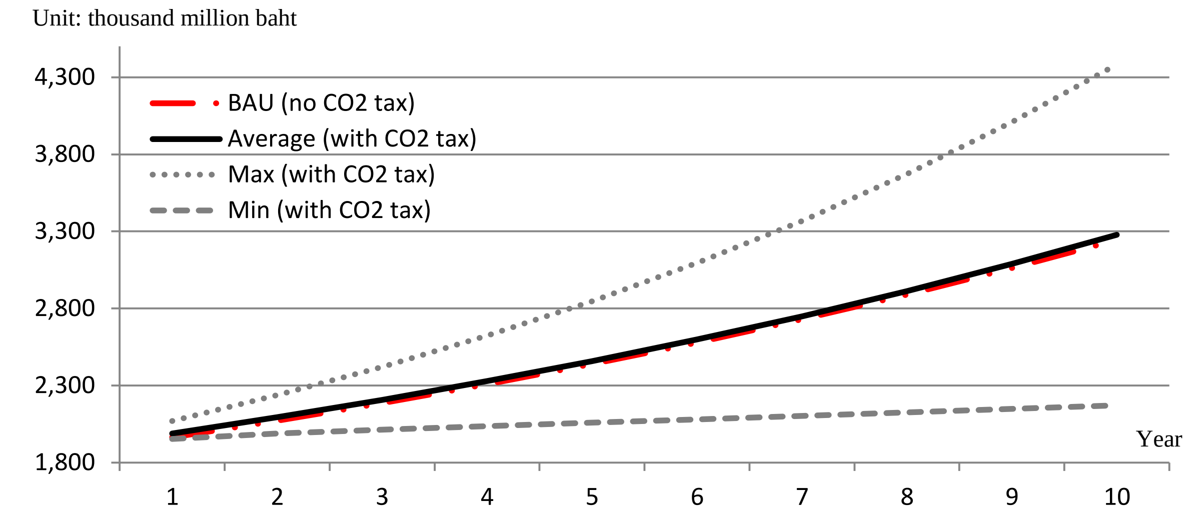

Figure 16. Statistical distribution of total government's revenue(with the tax rate of 445.49 baht) obtained from Monte-Carlo simulation.

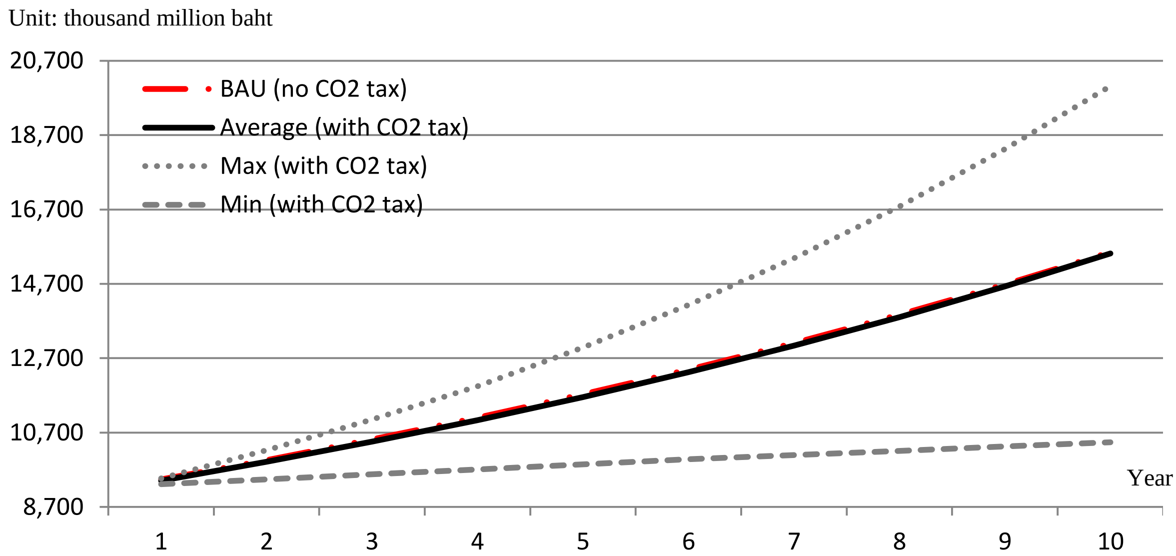

Figure 17. Statistical distribution of total household's revenue(with the tax rate of 445.49 baht) obtained from Monte-Carlo simulation.

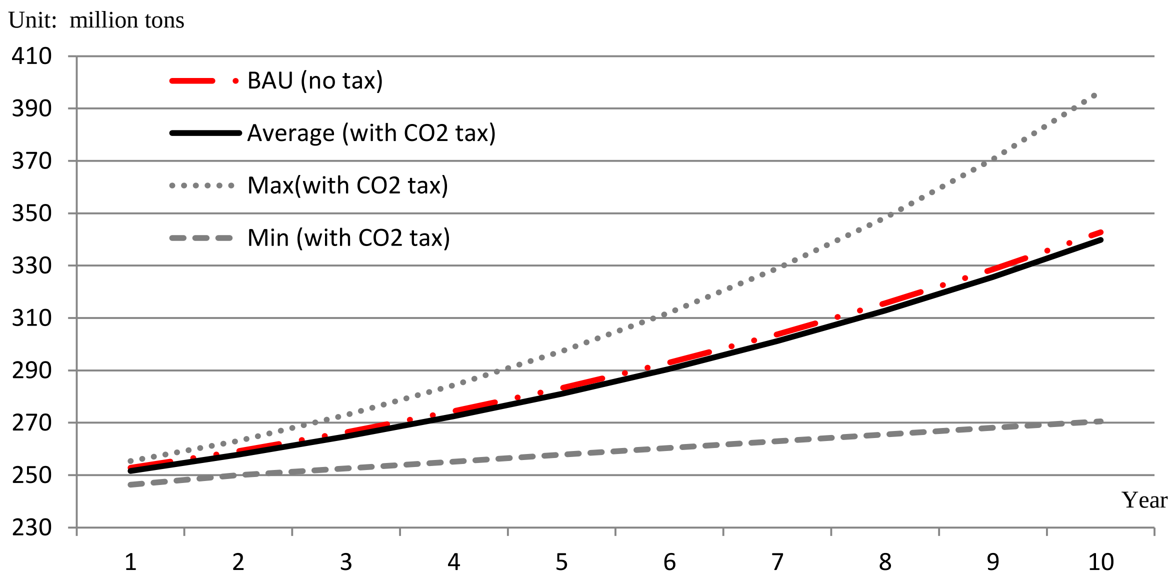

Figure 18. Statistical distribution of total CO_2 emission with the tax rate of 445.49 baht) obtained from Monte-Carlo simulation.

5. Conclusion

This study examines economy-wide impacts of imposing the carbon tax on producers whose production process emits CO_2. The first analysis, conducting the static simulation with three tax rates, shows that imposing the carbon tax on producers yields the negative impacts on Thai economy. Specifically this tax imposition causes the contraction of aggregate supply, resulting in the lowered real GDP, higher unemployment, lowered consumption and higher inflation. In the second simulation, this study incorporates the recursive dynamic CGE model with Monte-Carlo technique. This feature enhances the capability of CGE model to perform stochastic analysis. Results from Monte-Carlo simulation shows that total employment is the most sensitive variable to the given stochastic shocks, while the CO_2 emission and inflation are the least volatile values. These outcomes suggest the guideline for policy formulation regarding the imposition of carbon tax in Thailand. Particularly the reallocation of the government's revenue from the carbon tax is required to lessen the negative impacts, especially the contraction of employment and production activities. Also results generated by the dynamic stochastic simulation indicate that the outcome will have a larger variation in long-run. Therefore, the policy maker should continuously monitor and evaluate the impacts of the carbon tax policy in order to revise the regime that is suitable for the changing circumstances in the future.

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Appendix

List of commodities

com1	Paddy	com26	Gasoline
com2	Corn	com27	Jet fuel
com3	Cassava	com28	LPG
com4	Cane	com29	Diesel
com5	Oil Palm	com30	Fuel oil
com6	Livestock	com31	Other refinery product
com7	Charcoal	com32	Gasohol
com8	Fishery	com33	Biodiesel
com9	Other agricultural goods	com34	Rubber
com10	Coal and Lignite	com35	Non-metal
com11	Crude oil	com36	Iron
com12	Natural gas	com37	Metal
com13	Mineral	com38	Motor
com14	Food	com39	Machine
com15	Palm oil	com40	Other manufacturing good
com16	Rice	com41	Electricity
com17	Starch	com42	Property
com18	Maize	com43	Trade
com19	Sugar	com44	Rail transport
com20	Molasses	com45	Road transport
com21	Textile	com46	Water transport
com22	Wood	com47	Air transport
com23	Paper	com48	Other transport
com24	Ethanol	com49	Service
com25	Chemical product		

List of activities

sec1	Paddy	sec21	Paper
sec2	Corn	sec22	Ethanol
sec3	Cassava	sec23	Chemical product
sec4	Cane	sec24	Refinery
sec5	Oil Palm	sec25	Rubber
sec6	Livestock	sec26	Non-metal
sec7	Charcoal	sec27	Iron
sec8	Fishery	sec28	Metal
sec9	Other agricultural goods	sec29	Motor
sec10	Coal and Lignite	sec30	Machine
sec11	Crude oil and Natural gas	sec31	Other manufacturing good
sec12	Mineral	sec32	Electricity
sec13	Food	sec33	Construction
sec14	Palm oil	sec34	Trade
sec15	Rice	sec35	Rail transport
sec16	Starch	sec36	Road transport
sec17	Maize	sec37	Water transport
sec18	Sugar	sec38	Air transport
sec19	Textile	sec39	Other transport
sec20	Wood	sec40	Service