วารสารเศรษฐศาสตร์ธรรมศาสตร์ **Thammasat Economic Journal**
ปีที่ 31 ฉบับที่ 3 กันยายน 2556 **Vol. 31, No. 3, September 2013**

Impacts of Climate Change on Major Crop Yield and the Thai Economy : A Nationwide Analysis Using Static and Monte-Carlo Computable General Equilibrium Models

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Abstract

Climate change is a major concern for developing countries because changing weather conditions would significantly affect agricultural production output. Employing half of its total labor supply and land in agricultural activities, Thailand is considered one of the major food-exporting countries vulnerable to climate change. Despite the forecast of future weather volatility and its effect on Thailand's major crop yield such as rice, cassava, sugar cane, and corn, there is a lack of studies examining the resulting nationwide economic impact. This study aims to explore the economy-wide impacts of crop yield fluctuation on the Thai economy by using both static and Monte-Carlo CGE models. For effects on agricultural markets, simulation results indicate that prices and quantities of corn and cassava are the most sensitive to weather oscillation. In the nation-wide impact, both static and Monte-Carlo CGE models show that rice is the most significant crop because its volatility in price and quantity causes the highest impact

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and fluctuation on both the macro level and in terms of income distribution. The Monte-Carlo CGE model demonstrates that the fluctuation of impact on government and institutions can be reduced when volatilities of all four crop outputs are pooled. This suggests the possibility to design a crop insurance scheme to minimize the impact of volatility through risk pooling.

Keywords: Monte-Carlo, CGE Model, climate change, crop yields, income distribution, crop insurance, risk diversification

JEL classifications: C68, D58, O13, Q10, Q54

1. Introduction

Agriculture has been the Thai economy's main activity for centuries. In 2010, Thailand's Ministry of Agriculture and Cooperatives (MoAC)[1] reported that 71.1% of arable land was utilized for growing four main crops: sugar cane, cassava, and corn. According to the Food and Agriculture Organization (FAO) of the United Nations statistics for 2010[2],Thailand was the world's largest exporter of rice and cassava, and the second largest of sugar cane.

In 2010, the Fiscal Policy Research Institute of Thailand's Ministry of Finance conducted a study on rural socio-economy conditions. This study indicates that 29.2% of total households are involved in the production of these four main crops, and 46.1% and 38.7% of farmer households in the Northeastern and Northern regions are indebted from agricultural loans. The study concludes that the amount of farmer household debt is significantly influenced by the quantity and price of main crops, directly correlated with weather volatility, pests, and diseases. Similarly in 2008, the MoAC reported that the extreme weather can impact socio-economic conditions. The severe drought that year caused income problems for 17.9% of all farmer households.

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[1] http://eng.moac.go.th/main.php?filename=index

[2] http://faostat.fao.org/site/567/default.aspx#ancor

Based on these facts, weather volatility is a major factor affecting rural socio-economic conditions. The MoAC is authorized to administrate the mitigation scheme, which includes verification of crop losses and allocation of agricultural subsidies. According to the MoAC report, the total amount of subsidies for crop losses increased by fivefold from 2005 to 2008, and this amount subsequently continued to increase.

With the trend of increasing weather volatility, the government subsidy for crop losses will likely increment and cause future fiscal burdens. This paper aims to explore the economy-wide impact of weather volatility on the Thai economy, particularly through agricultural production, and examine the possibility of developing crop insurance to lessen future fiscal burdens. This paper is the first study of Thailand that incorporates results generated by climate simulation and a crop-yield model with the CGE model. It is also the first to use Monte-Carlo simulation to explore stochastic impacts on the Thai economy.

The paper is structured as follows: the second part reviews related literature. The third part discusses details of data sources and simulation inputs. The fourth section outlines the main structure of the CGE model and simulation technique. The fifth part discusses results generated by static and Monte-Carlo simulations. The last section concludes all key findings.

2. Literature Review

Darwin (1995) was among the first to examine the impact of crop yield volatility on agricultural markets. Boussard and Christensen(1999) constructed the model that demonstrates the impact of agricultural price volatility on economies of Poland and Hungary. Arndt (1999) used the similar analytical framework to study economic impacts of drought on African countries, and Arndt and Tarp (2000) employed the same model to explore the economic fluctuation of Mozambique caused by volatility of cassava production. Among developed economies, Burfisher et al. (2000) studied the impact of agricultural production volatility on North American economies.

Influenced by the development of climate modeling, many studies link climate simulation with the CGE model. Harris and Robinson (2001) were among the first to integrate the climate simulation of El Nino and La Nina with a CGE model to explore their impacts on the agriculture and overall economic conditions in Mexico. Since then, many studies have followed this analytical framework. Pauw et al. (2010) examined the impact of weather volatility on Malawi's economy. Thurlow (2010) explored weather impact on Zambia. Zhai (2010) applied a similar analysis to China. Nelson et al.(2010) conducted the study examining the global relationship between climate change and international food markets. Bosello and Zhang (2005) published the survey of related literature in this field. In the case of Thailand, models projecting future volatility of weather caused by climate change have been continuously developed. Tangtham (2005) and SEA START (2008) produced models projecting future climate scenarios. Sorawat (2009), Pannangpetch (2010) and Buddhaboon (2010) used these simulated climate scenarios to develop crop-yield models estimating the future volatility of major crop yields. Integration of crop yield volatility caused by climate change to the economic model does not yet exist. This paper aims to bridge this gap by using the existing scenarios of crop-yield volatility as input for the CGE model to explore economy-wide impact in Thailand.

3. Data

Two main sources of data are

1) The projected yield volatility of rice, cassava, sugar cane, and corn in Thailand, generated by SEA START (2008) 's climate scenarios and Pannangpetch (2010)'s crop models. These data are inputs for the CGE model representing changing productivity of main crop production.

2) The data set for the CGE are model mainly from the National Economic and Social Development Board's national account and from the Social Accounting Matrix of 2008 produced by the Office of Agricultural Economics of the MoAC. Data used as the base case of the model

includes 42 production sectors, 5 groups of households, the aggregate representative of corporations, the government and international trade.

4. Methodology

Because the main objective of this study is to examine the economy-wide propagation of impacts initiated by crop-yield volatility, the CGE model is selected as the main tool that can reveal adjustment of all markets and institutions in the economy. The CGE model structure follows the standard model introduced by Lofgren et al. (2002), which enables adjustment of price and quantity of most goods and input factors. In this study, the main assumptions of the CGE model include[3]:

- Producers have the main purpose to maximize profit and production behavior under the constant-return-to-scale condition.
- Consumers aim at maximizing under budget constraints, and deciding about 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, tax rates, and governmental consumption are specified as exogenous variables representing policy instruments.
- Unemployment exists in the labor market, and capital utilization maybe below the fully utilized rate.

[3] Full details of the CGE model are available upon request.

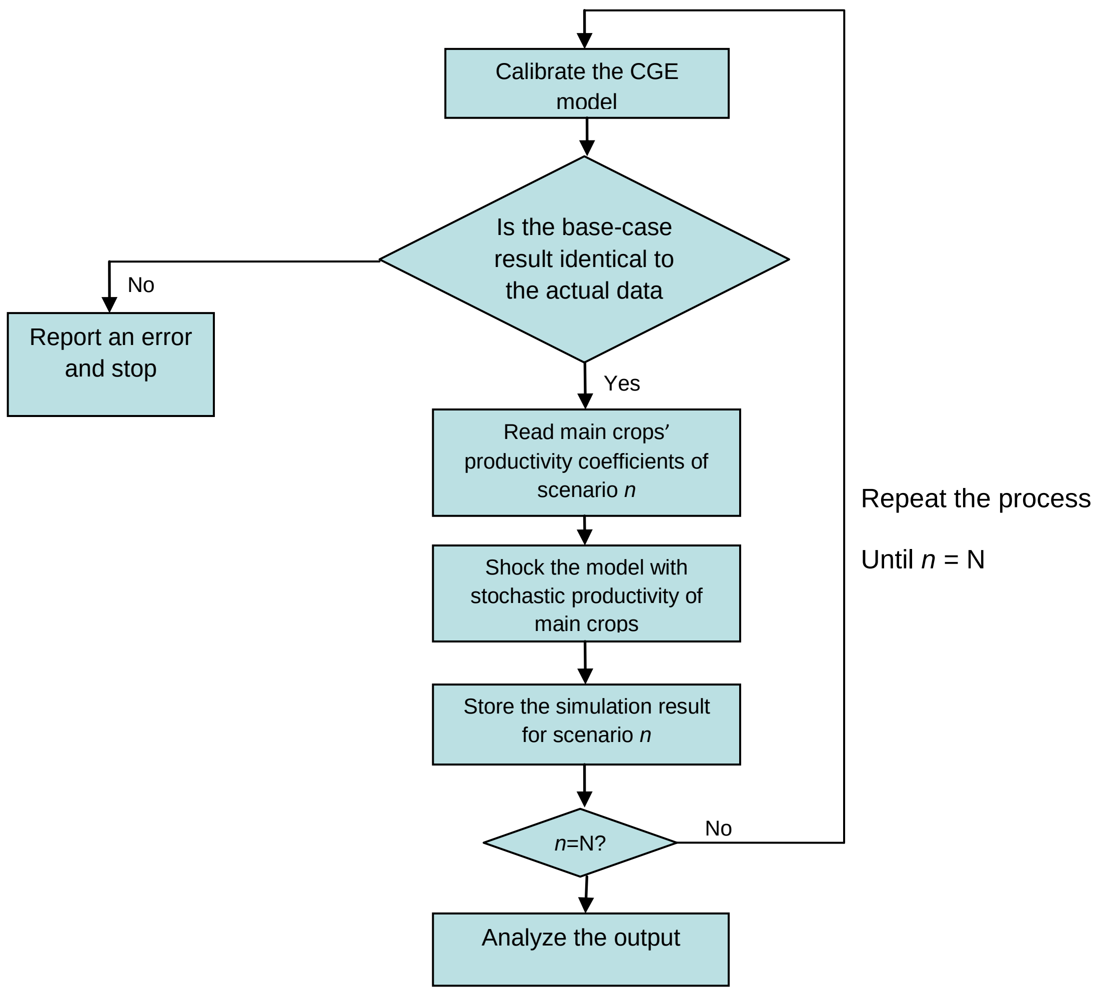
- Institutions in the model include five groups of households, the government, the aggregate representative of corporations, and the rest of the world.

The first set of simulations uses the CGE model to examine the economy-wide impact when the yields of rice, cassava, corn and sugar cane are increased or decreased. The productivity index of the each crop's production is changed to represent varying yields.

In addition to conducting static analysis, the CGE model expanded to perform a Monte-Carlo simulation. This new capability allows the model to repeatedly solve a system of equations with parameters and exogenous variables with values randomly distributed under a given stochastic property. Technically speaking, the standard 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 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. Specifically, within the loop, the process starts with assigning a new set to values of parameters and exogenous variables; the model will compute a new solution representing values of a new equilibrium of the economy under this given condition. After computation, the solution is stored and the model repeats the same procedure by fetching the next set of values for parameters and exogenous variables representing the new scenario. This computational loop will repeat until it reaches the last set of parameters values and exogenous variables. In the final process, the stochastic property 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 before running the Monte-Carlo simulation of CGE on GAMS.

Figure 1

Main process of Monte-Carlo Simulation



In this study, the yield variation of rice, cassava, corns, and sugar cane is an input, representing stochastic shocks caused by climate volatility. The distribution properties of these main crops are obtained from Pannangpetch (2010), simulating a forecasted variation of crop yields from1980 to 2079.

5. Results

Two sets of simulations are conducted in this study. The first is a static simulation, exploring nation-wide impacts of increasing and decreasing yields of four major crops. The second is the Monte-Carlo simulation, showing the set of solutions when the model is repeatedly shocked with 100 different values of crop yields, randomly selected from a given distribution. Because the model includes 1,639 endogenous variables, only simulation results of key endogenous variables are exhibited and discussed. The sets of selected endogenous variables are (1) the adjustment of price and quantity in the market of specific crops, (2) impact on key macro variables and (3) effect on institutional saving.

5.1 Results from static simulation

Each main crop's yield is varied by increasing and decreasing Total Factor Productivity (TFP) of the production function by 5%.

5.1.1 The adjustment of price and quantity in crop markets

Table1 shows that the price elasticity of rice, cassava, and corn is close to the value of 1.0, similar to the result reported by empirical studies[4]. However, in the case of sugar cane, it is found that its price elasticity is much higher than that of other crops. Because rice, cassava, and corn are substitutable as carbohydrate sources, but sugar cane is the only main natural sweetener for production and consumption in Thailand. Therefore the price elasticity of sugar cane is higher than that of other main crops.

[4] For example, Meenaphant (1981).

In addition to the value for price elasticity, the model's non-linearity property also generates an interesting result. In this set of simulations, although productivity shocks are symmetric (with identical magnitudes in negative and positive directions), results show asymmetric responses of the economy to shocks. In all cases of simulations, magnitudes of responses to declining yields are higher.

Table 1

Responses of price and quantity to changes in productivity of main crops

	Rice Cultivation		Corn Cultivation		Cassava Cultivation		Sugar Cane Cultivation	
	+5% TFP	-5% TFP	+5% TFP	-5% TFP	+5% TFP	-5% TFP	+5% TFP	-5% TFP
Price adjustment	-3.29%	3.63%	-3.48%	3.82%	-2.78%	3.04%	-4.89%	5.44%
Quantity adjustment	3.19%	-3.30%	3.71%	-3.78%	2.71%	-2.80%	2.82%	-2.92%

5.1.2 Impacts on macro variables

Table 2 illustrates interesting consequences of varying crop yields on the macro level. According to results of price and quantity adjustment shown in 5.1.1, values of price elasticity for most crops are close to 1.0, implying that the net effect would be neutralized due to the opposite adjustment of price and quantity. However, macro variables indicate that overall impacts on the economy are not neutral. Table 2 shows that adjustment of all macro indicators follows the direction of crop yields. The magnitude of impact for rice is the highest, and those of sugar cane, corn and cassava have macro effects in declining order of size. This result follows the actual structure of the Thai economy, in which a large proportion of arable land and labor is contributed to rice cultivation. Similar to the result in 5.1.1, the non-linear characteristic of the model shows that the magnitude of declining crop yields has the greater macro impacts than those of rising-yield cases, especially the adjustment of real GDP and employment. Simulation results for all cases indicate that effects on the aggregate output (i.e. real GDP) and aggregate price (i.e. consumer price index) are in the opposite direction, following the theoretical concept of aggregate responses to the supply shock.

Table 2

Adjustment of key macro variables to changes in productivity of main crops

	Rice Cultivation		**Corn Cultivation**		**Cassava Cultivation**		**Sugar Cane Cultivation**	
	+5% TFP	-5% TFP	+5% TFP	-5% TFP	+5% TFP	-5% TFP	+5% TFP	-5% TFP
Real GDP	0.17%	-0.20%	0.04%	-0.04%	0.03%	-0.03%	0.09%	-0.11%
Consumer Price Index (CPI)	-0.18%	0.22%	-0.04%	0.04%	-0.03%	0.03%	-0.10%	0.12%
Total Consumption	0.15%	-0.18%	0.03%	-0.03%	0.02%	-0.02%	0.07%	-0.09%
Total Export	0.13%	-0.15%	0.03%	-0.03%	0.02%	-0.02%	0.07%	-0.09%
Total Import	0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%
Total Employment	0.43%	-0.55%	0.09%	-0.10%	0.05%	-0.06%	0.26%	-0.32%

5.1.3 Impacts on institutional saving

Since the CGE model features all adjustments throughout the economy, the impact on institutional welfare is an interesting issue, especially for the economies in which agricultural activities employ a large proportion of land and labor supply. A variation in prices, quantities of goods, and production factors affects income and expenditure of each institution. Hence, savings, computed in real term, are used as a proxy of net effect on five classes of households, the government, and the aggregate corporate representative. Table 3 indicates that increasing yields of all crops lead to a positive impact on all institutions while lowering yields bring negative consequences. The model's non-linear structure shows that in all cases, magnitudes of negative impacts are greater than those of positive ones. For income distribution, the highest-income household (i.e. household group 5) has the largest impact magnitude, while households of group 1 to 4 always experience almost identical impacts because their structures of income and expenditure are similar. The simulation also indicates that variation of rice yield has the biggest impact on institutional saving, while that of sugar cane, corn, and cassava has a smaller size of impacts, in declining order.

Table 3

Adjustment of institutional savings to changes in productivity of main crops

	Rice Cultivation		Corn Cultivation		Cassava Cultivation		Sugar Cane Cultivation	
	+5% TFP	-5% TFP	+5% TFP	-5% TFP	+5% TFP	-5% TFP	+5% TFP	-5% TFP
Household group 1	0.0041%	-0.0050%	0.0006%	-0.0006%	0.0009%	-0.0010%	0.0031%	-0.0037%
Household group 2	0.0041%	-0.0050%	0.0006%	-0.0006%	0.0009%	-0.0010%	0.0031%	-0.0037%
Household group 3	0.0041%	-0.0050%	0.0006%	-0.0006%	0.0009%	-0.0010%	0.0031%	-0.0037%
Household group 4	0.0041%	-0.0050%	0.0006%	-0.0006%	0.0009%	-0.0010%	0.0031%	-0.0037%
Household group 5	0.0080%	-0.0108%	0.0018%	-0.0021%	0.0001%	-0.0003%	0.0029%	-0.0041%
Government	0.1801%	-0.2320%	0.0533%	-0.0589%	0.0364%	-0.0414%	0.1353%	-0.1626%
Corporate	0.0811%	-0.1032%	0.0136%	-0.0152%	0.0123%	-0.0143%	0.0523%	-0.0635%

5.2 Results from the Monte-Carlo simulation

To extend the model's capability to stochastic analysis, the standard CGE model has been modified to perform the Monte-Carlo simulation, repeatedly solving the model with a set of randomly generated parameters and exogenous variables. As stated in section 4, the variation of crop yields used as randomized parameters for the Monte-Carlo simulation is obtained from Pannangpetch (2010). Table 4 exhibits the distribution property of rice, corn, cassava and sugar cane yields caused by projected climate volatility. The Monte-Carlo simulation in this study conducts 100 scenarios with the crop yields under these specified distribution properties:

Table 4

Distribution property of yields of main crops

	Rice Cultivation	**Corn Cultivation**	**Cassava Cultivation**	**Sugar Cane Cultivation**
Mean (tons/hectare)	2.77	3.12	20.20	62.38
Standard Deviation (tons/hectare)	1.03	0.68	3.19	18.63

5.2.1 Adjustment of price and quantity in crop markets

For results obtained from Monte-Carlo simulations, the Coefficient of Variation is used as a measure of degree of variation, enabling us to compare volatility of endogenous variables. Specifically, the Coefficient of Variation is the ratio of standard deviation to the mean. In this study, five sets of Monte-Carlo simulations are conducted. Simulation 1is the case where 100 randomized values of the productivity index (TFP) for rice are the stochastic shocks to the model, generating 100 result scenarios. Similarly, Simulations 2 to 4 are simulations with randomized values of productivity indexes for corn, cassava and sugar cane, respectively. Simulation 5 is the special case where the economy encounters stochastic shocks of all four crop yields simultaneously. Table 5 shows the results from all Monte-Carlo simulations, focusing on the impacts of price and quantity adjustments. Unlike the results obtained from static simulation, volatilities of prices and quantities of corn and cassava are higher than those of rice and sugar cane.

Table 5

The distribution property of responses of price and quantity to stochastic shocks of crop yields

	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
	Stochastic shock of rice yield	Stochastic shock of corn yield	Stochastic shock of cassava yield	Stochastic shock of sugar cane yield	Stochastic shock of all crop yields
Price of rice (S.D./Mean)	9.72%	0.28%	0.15%	0.02%	9.83%
Price of corn (S.D./Mean)	0.90%	17.92%	0.21%	0.03%	18.21%
Price of cassava (S.D./Mean)	0.60%	0.28%	16.21%	0.02%	16.23%
Price of sugar cane (S.D./Mean)	0.76%	0.37%	0.18%	9.36%	9.17%
Quantity of rice (S.D./Mean)	9.67%	0.30%	0.16%	0.02%	9.81%
Quantity of corn (S.D./Mean)	1.03%	17.23%	0.24%	0.04%	17.59%
Quantity of cassava (S.D./Mean)	0.67%	0.33%	14.33%	0.07%	14.29%
Quantity of sugar cane (S.D./Mean)	0.76%	0.38%	0.23%	7.45%	7.26%

5.2.2 Impacts on macro variables

For volatilities of macro variables, Table 6 indicates that varying rice yield causes the highest economic volatility, while that of corn, cassava and sugar cane has a lower degree of volatility impacts, in declining order. In Simulation 5, volatility generated by rice yield variation still dominates stochastic impacts caused by all four crops. Interestingly, the Coefficient of Variation of unemployment declines when risks from all crops are pooled. This finding reveals a special mechanism in the labor market which can mitigate the negative impact caused by crop yields volatility.

Table 6

The distribution property of key macro variables in response to stochastic shocks of crop yields

	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
	Stochastic shock of rice yield	Stochastic shock of corn yield	Stochastic shock of cassava yield	Stochastic shock of sugar cane yield	Stochastic shock of all crop yields
Real GDP(S.D./Mean)	0.327%	0.217%	0.108%	0.021%	0.335%
Consumer Price Index (CPI)(S.D./Mean)	0.395%	0.255%	0.129%	0.018%	0.403%
Total Consumption(S.D./Mean)	0.241%	0.205%	0.098%	0.006%	0.275%
Total Export(S.D./Mean)	0.248%	0.162%	0.073%	0.020%	0.249%
Total Import(S.D./Mean)	0.048%	0.036%	0.012%	0.006%	0.053%
Total Employment(S.D./Mean)	1.963%	1.066%	0.376%	0.091%	1.940%

5.2.3 Impacts on institutional savings

Table 7 illustrates stochastic impacts on institutional savings. Similar to results shown on 5.2.2, the Coefficient of Variation caused by fluctuating rice yields has the greatest impact on all institutions. In Simulation 5, when pooling volatility of yields for all crops, fluctuation originating from rice yields dominates all others. In all simulations, governmental savings face the highest volatilities according to its Coefficient of Variation. Simulation 5 shows that volatility of governmental savings and that of the highest-income household can be reduced by pooling variations of all crop yields. These findings point to the possibility of designing the crop's risk diversification scheme in Thailand. In addition, the result in 5.2.2 shows that risk pooling can also lessen volatility of unemployment. These results suggest that an embedded mechanism of volatility mitigation is inherent in the Thai economy, automatically lowering standard deviation when risks are pooled. Future research should examine details of this mechanism.

Table 7

The distribution property of institutions' saving in response to stochastic shocks of crop yields

	Simulation 1	**Simulation 2**	**Simulation 3**	**Simulation 4**	**Simulation 5**
	Stochastic shock of rice yield	Stochastic shock of corn yield	Stochastic shock of cassava yield	Stochastic shock of sugar cane yield	Stochastic shock of all crop yields
Household group 1	0.0215%	0.0122%	0.0067%	0.0010%	0.0221%
Household group 2	0.0215%	0.0122%	0.0067%	0.0010%	0.0221%
Household group 3	0.0216%	0.0122%	0.0067%	0.0010%	0.0222%
Household group 4	0.0216%	0.0122%	0.0067%	0.0010%	0.0222%
Household group 5	0.0304%	0.0162%	0.0004%	0.0024%	0.0292%
Government	0.8601%	0.3953%	0.2071%	0.0197%	0.8375%
Corporate	0.3926%	0.2187%	0.0932%	0.0219%	0.3942%

6. Conclusion and Policy Inference

This study delivers two main conclusions. Firstly, it bridges the gap between scientific analysis and economic modeling by linking results from weather and crop models with the CGE model. Secondly, this study introduces the Monte-Carlo technique to CGE modeling, extending the model's capability to illustrate the impact on the economy in the stochastic dimension.

By using crop yield volatility as CGE model input, the first simulation shows that variation of yield for four main crops initiates a supply-side shock to the whole economy. Volatility of rice yield has the highest impact to the economy. The non-linear structure of the model also indicates that with the symmetric shock of crop yield, responses are asymmetric. Specifically, the magnitude of response to negative shock is greater than that to a positive one.

The Monte-Carlo CGE shows that rice yield contributes the highest degree of volatility to the economy. This simulation also indicates that standard deviation of employment, highest-income household savings, and governmental savings can be reduced by pooling volatilities for all crop yields. Future research should explore details of developing agricultural risk management through diversification across crops and locations. As many households cultivates the four main crops and weather volatility is an important factor affecting incomes, innovations and implications of new mitigation framework by risk diversification would help to arrive at future sustainable development for Thailand.

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