Asset management of public facilities in an era of climate change: application of the dynamic computable general equilibrium model

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Abstract

Agricultural production depends heavily on climate conditions; therefore, climatic uncertainty caused by global warming represents a significant threat not only to agriculture but also to entire economies. Furthermore, the drastic budget cuts after 2001 in Japan have reduced public capital stock and have placed the production capacities of various industries in jeopardy. This highlights the need for asset management to prolong the structural integrity of facilities. The present study uses the recursive dynamic computable general equilibrium (CGE) model to evaluate asset management measures (namely, those focusing on reinforcing old facilities) in the context of climatic uncertainty. Simulation results showed that the uncertainty of production induced by climate change is amplified through the market mechanism. The variation in the total production was much wider than the variation in agricultural production originally affected by the climate change. The public capital stock maintained by the asset management measures can ease such uncertainty. Therefore, asset management policy, which makes the deficit minimal leeway for increasing public investment, is critical in Japan. The dynamic CGE model can also measure such long-term comprehensive effects and is useful for policy analysis.
Keywords: computable general equilibrium model, recursive dynamic model, asset management measures, public investment, public capital stocks, Hicksian equivalent variation.

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1 Introduction

The fourth report of the International Panel for Climate Change (IPCC) cautioned about the seriousness of precipitation and temperature variation due to global warming. Global warming has the potential to devastate agriculture, for which climactic regularity has obvious importance, and could also adversely affect other sectors. Such possibility raises an urgent need to consider the economic and industrial impact of climate change.

Production levels are determined by the public capital stocks, such as irrigation canals, roads, and flood control banks, as well as input factors, such as labor, private capital stocks, and land. Asset management measures can counter the unpredictability caused by global warming. One method is the fortification or renovation of existing structures, which prolongs their lifecycle and is more cost effective than constructing new facilities.

Previous studies estimated the aggregate production function to show the direct effect of the public facilities (Nakashima [6], Yokoyama and Kataoka [12]). They found that the production elasticity of public capital stocks was about 10% and that public investment stimulates the productivity of capital-intensive technology (i.e., labor-saving technology). However, the production function approach sheds light on the direct effects and cannot show the benefit of consumer side as a ripple effect.

The computable general equilibrium (CGE) model is used to analyze benefit transfer from producers to consumers on the basis of market price, supply, and demand. A number of researchers have employed the static CGE model. Saito [9] analyzed the effects of a farmland consolidation project, another type of agricultural public investment. Kunimitsu [5] measured the economic effects of irrigation and drainage facilities in Japanese agriculture. Conversely, Son et al. [11], Shibusawa et al. [10], and Ban [1] developed the dynamic CGE model to analyze transportation policies, environmental policies, and regional effects of policy change, respectively. The application of the dynamic CGE model is ideally suited for evaluating public facilities.

For this study, we use the recursive dynamic CGE model to show the comprehensive effects in economies. Three types of scenarios were considered to simulate climatic uncertainty and effects of the change in public capital stocks.

2 Methodology

2.1 Structure of the recursive-dynamic CGE model

The model used is the recursive dynamic version of the CGE model. The structure of our model is based on Ban [1], which uses GAMS (GAMS Development Corporation) with MPSGE (modeling tool using the mixed complementary problem) developed by Rutherford [7]. The equations of the model are as follows.

Zero-profit condition:

$$f_i^c(w, r, kg, tax, weather) = pd_i \quad \perp \quad Y_i \geq 0 \tag{1}$$

$$f_i^A(pm, pd) = pa_i \quad \perp \quad A_i \geq 0 \tag{2}$$

$$pfx = f^T(pm) \quad \perp \quad M_i \geq 0 \tag{3}$$

$$f^T(pe) = pfx \quad \perp \quad E_i \geq 0 \tag{4}$$

$$pk = f^u(pa) \quad \perp \quad I \geq 0 \tag{5}$$

$$pc = f^u(pa) \quad \perp \quad C \geq 0 \tag{6}$$

$$pcg = f^u(pa) \quad \perp \quad Cg \geq 0 \tag{7}$$

$$pig = f^u(pa) \quad \perp \quad Ig \geq 0 \tag{8}$$

Market clearance condition:

$$Y_i f_i^R(pd, pe) = A_i f_i^A(pm, pd) \quad \perp \quad pd_i \geq 0 \tag{9}$$

$$\sum A_i = G + C + I \quad \perp \quad pa_i \geq 0 \tag{10}$$

$$M_i = A_i f_i^A(pm, pd) \quad \perp \quad pm_i \geq 0 \tag{11}$$

$$Y_i f_i^R(pd, pe) = E_i \quad \perp \quad pe_i \geq 0 \tag{12}$$

$$\sum X_i - \sum M_i = \overline{Bdef} \quad \perp \quad pfx \tag{13}$$

$$I = f^u(pk, M_i) \quad \perp \quad pk \geq 0 \tag{14}$$

$$\overline{K} = Y_i \frac{\partial f^c(w, r, kg, tax)}{\partial r} \quad \perp \quad r \geq 0 \tag{15}$$

$$\overline{L} = Y_i \frac{\partial f^c(w, r, kg, tax)}{\partial w} \quad \perp \quad w \geq 0 \tag{16}$$

$$C = f^u(pc, M_i) \quad \perp \quad pc \geq 0 \tag{17}$$

Income restriction:

$$M = r\overline{K} + w\overline{L} + pf\,\overline{F} \tag{18}$$

$$G = pfx \cdot \overline{Bdef} + tax - pcg \cdot Cg - pig \cdot Ig \tag{19}$$

Here, i represents the classification of the industrial sector, and kg and tax are the public capital stocks relating to production and taxation. Y, A, M, E, I, C, Cg, and Ig are domestic production, Armington's composite good, imports, exports, investment, household consumption, government consumption, and public investment, respectively; pd, pa, pm, pe, pfx, rk, w, and pc are the price indexes corresponding respectively to domestic production, Armington's composite good, imports, exports, foreign currency, investment goods, rental cost of capital, wages, and consumption goods; *M*, *G*, *K*, and *L* are household income, government revenue, initial capital stock, and initial labour amount; and *weather* is variation of total factor productivity caused by the weather condition. Also, *f*(•) indicates a function, and superscripts of each function, that is, *c*, *a*, *r*, and *u* show cost function, the Armington function, profit function, and utility function, respectively.

The weather condition, *weather*, applies only to agriculture and is measured by the residues of estimated TFP function, ie. $\ln(TFP) = \alpha_0 + \alpha_1 \ln(Scale) + \alpha_2 \ln(kg \times R\,\&\,D)$. Here, *TFP* is the total factor productivity, *Scale* is the average management area of farmers and *kg* is the public capital stocks and *R&D* is the knowledge capital stocks accumulated by research. The *kg* in Eq. (1) is assumed to increase the TFP of the value-added sector with a production elasticity of 0.1. This means that if *kg* increases by 1%, the unit cost would decrease by 0.1%. In the equation, the cost function is multiplied by $(kg / kg\_ref)^{0.1}$, where *kg_ref* is the reference value of public capital stocks and kg is the simulated public capital stock. The value of production elasticity is derived from Yokoyama and Kataoka [12].

The functions used are all constant elasticity of substitution (CES) forms, including the Cobb-Douglas function and the Leontief function. Figure 1 shows the structure of cost function representing production structure (Eqs. (1)–(4)). Figure 2 shows the demand structure representing utility function (Eq. (6)). Figure 3 shows the government consumption and government investment (Eqs. (7) and (8)).

To form the recursive dynamic path, the capital stock equation is defined as follows.

Private capital stock:

$$K(t) = (1-\delta)K(t-1) + I(t) \tag{20}$$

Public capital stock:

$$kg_j(t) = (1-\delta_g)kg_j(t-1) + IG_j(t) \tag{21}$$

Here, δ and δg represent the depreciation rate, set as 0.04 and 0.025.

The elasticity values of substitution(*s*) in the production, consumption, import, and export functions are set at the same values enumerated in Ban [1], which were based on the GTAP database. The elasticity of substitution of farmland to other input factors in agriculture is assumed to be 0.1. Since the production per area in Japanese agriculture has been stable for many years even as total farmland area diminishes, we concluded that farmland is a semi-fixed input for agricultural production and cannot be substituted by other factors.

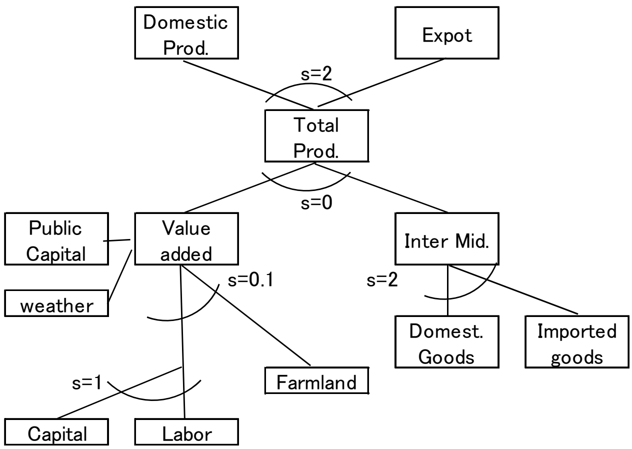

Figure 1: Outline of production in the CGE model.

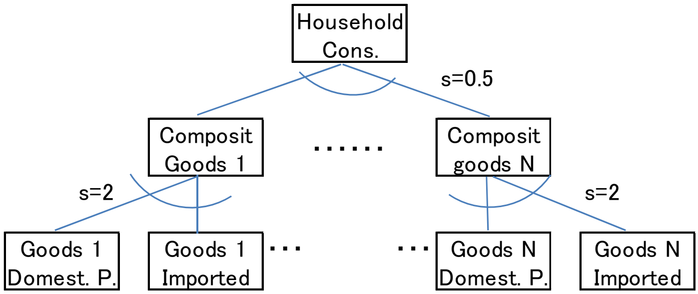

Figure 2: Outline of household consumption in the CGE model.

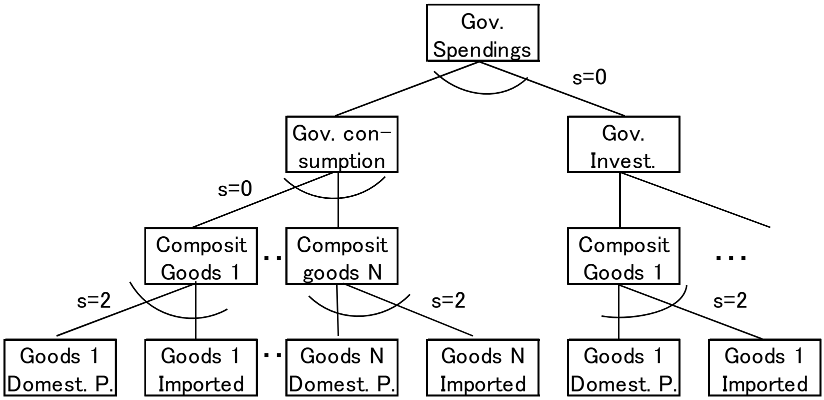

Figure 3: Outline of government behaviour in the CGE model.

2.2 Data

To calibrate the parameters of the model, the social accounting matrix (SAM) was estimated on the basis of the 2005 Input-Output Table of Japan, using a method derived from Hosoe et al. [3]. The sectors used here are paddy; husbandry, forestry, and fishery; the food processing industry; mining; manufacturing; and the service sector.

The factor input value of farmland, which was not shown in the Japanese I/O Table, was taken from the GTAP 7 database. Then, it was subtracted from the operating surplus. The factor input value of capital was calculated by adding the operating surplus and the depreciation value of capital.

2.3 Simulation

In order to quantify the effects of policy change, the following three scenarios were considered with respect to asset management policy.

Base Line (BL) Case: Status quo, which is shown by the present SAM data without climatic uncertainty.

Climatics Uncertainty (CU) Case: Status quo with climatic uncertainty. In this case, climatic uncertainty represented by *weather* is introduced in the cost function.

Asset Management and Climatic Uncertainty (AM + CU) Case: Asset management measures were conducted under climatic uncertainty. The depreciation rate of public capital is decreased by 17% owing to the asset management measures. This rate was measured by Kunimitsu [4] in the field survey data.

In each case, the simulation period was 25 years from 2005 to 2030. The growth rate of exogenous variables, such as population and labour force, was assumed to be 0% per year and interest rate was set as 3.5% after considering the present situation of Japan.

For evaluation of policy change in view of the social welfare level, the Hicksian Equivalent Variation (HEV) was calculated from the simulation results as follows:

$$HEV \equiv ep(pcp_0, UU_1) - ep(pcp_0, UU_0) \tag{22}$$

Here, $ep(\cdot)$ shows the expenditure function derived from the maximization of utility level (UU). pcp is the price of consumption goods. The suffixes 0 and 1 show the reference case and comparing case.

3 Results

3.1 Effects of climatic uncertainty

Figure 4 shows the production change caused by the climatic uncertainty. The level of agricultural production was calculated by adding paddy domestic production and domestic production of other agriculture. The total production was the sum of domestic production, including agricultural production. The smooth lines (Agri_BL case and Total_BL case) are the simulation results without considering the effects of climatic change represented by *weather*. On the other hand, the zigzag lines with annual variation (Agri_CU case and Total_CU case) correspond to the simulation results relating to climatic uncertainty. The lines marked "Total" are measured by the left-side axis and the lines labelled "Agri" are measured by the right-side axis. Both axes are drawn according to the same scale, though the levels are different.

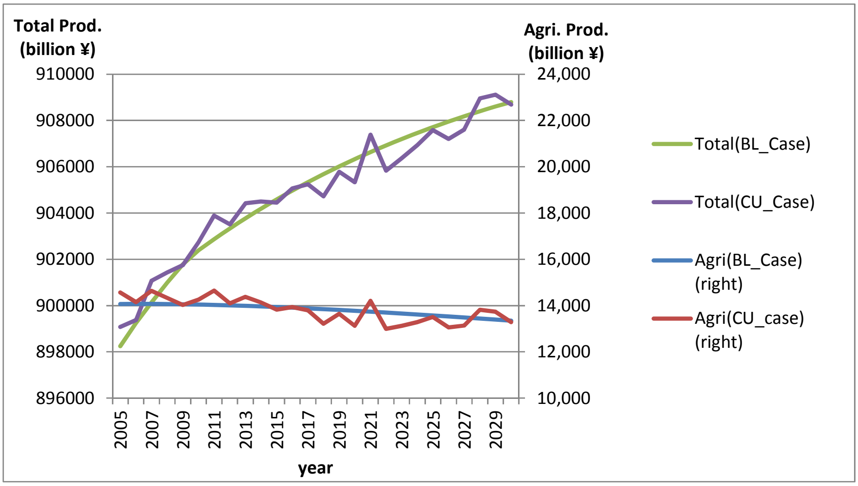

Figure 4: Production change caused by climatic uncertainty.

The annual variation in the total production (Total_CU subtracted by Total_BL) was larger than that of agricultural production (Agri_CU subtracted by Agri_BL). To compare the probability of variation between the two, we calculated the percentile values on the basis of annual differences. The width between the 90% percentile value and 10% percentile value was 1065 (=482 – (–583)) for agriculture and 1686 (=786 – (–896)) for total. The agricultural sector was the sole factor contributing to variation in total production. Hence, the difference in variations shows that the market mechanism amplifies the production uncertainty of the agricultural sector, which faces climatic change.

3.2 Contribution of the asset management measures

Figure 5 shows chronological trend of Hicksian EV values. As shown by the difference between the zigzag line in the CU case and the smooth line in the BL case, EV was vibrated by the climatic uncertainty. Although the line in the CU + AM case, which introduced the asset management measures, was not smooth, this line was located at a higher level than other lines. Even during inauspicious climate conditions (i.e., in 2020, the level of EV with the asset management measures was higher than the BL case. Hence, the asset management measures can buffer against risk brought on by climatic uncertainty by improving total factor productivity in each industry.

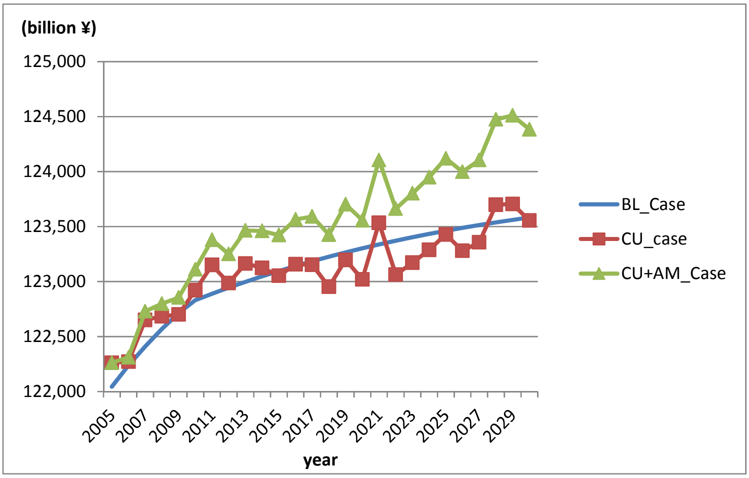

Figure 5: HEV with and without the climatic uncertainty.

4 Discussion

This study evaluated changes in production caused by climatic uncertainty and the effects of asset management measures, namely, reinforcing pre-existing facilities. The recursive dynamic CGE model was utilized to show their comprehensive effects represented by the changes in the price and quantity at economic equilibrium. Three types of scenarios were analyzed to simulate climatic uncertainty and the effects of the change in public capital stocks.

Simulation results showed that production uncertainty due to climate change is amplified through the market mechanism. Total production exhibited a much wider degree of variation than that of the agricultural production that was originally affected by the climate change. The public capital stock maintained by the asset management measures help compensate for such uncertainty.

Asset management policy is critical in Japan, where increasing public investment is unlikely given the country's immense financial deficit. Efficient measures in both economics and environmental policy are necessary to maintain sustainable economic development. The results of this study make clear that asset management measures that target public facilities can contribute to two distinct goals. Policymakers should more strongly advocate asset management measures instead of more costly construction projects.

The macroeconomic view seems to discourage funding asset management measures by taxing the population, as suggested by the dynamic CGE model. The CGE approach is especially relevant as an analytical tool, considering the limitation of natural resources with which humanity must contend.

However, several issues need to be addressed. First, our CGE model is designed specifically for Japan and does not account for variations between different locations, so multi-regional analysis may not be viable. Second, the environmental sustainability may be measured by the CGE framework by integrating environmental aspects with our model. Third, our model would necessitate further refinement of its financial components in order to accommodate the effects of global capital drift that occur in the real world.

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