Economic impacts of long-term climate change on rice production and farmers' income: Evidence from computable general equilibrium analysis

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Abstract

Future climate change will affect rice production, but whether these changes will be beneficial or detrimental is unclear. The present study evaluates the effect of climate change on Japanese rice production, farmers' income, and regional economies by using the recursive-dynamic regional computable general equilibrium (CGE) model. This model is associated with crop-growth models, hydrological models, and global climate models. The simulation results demonstrate that future climate change will increase Japanese rice production for the country as a whole, but that the price of rice will decrease. As a result, the income of farmers in the rice sector will decrease, despite the increase in production. Furthermore, climate change will not benefit the northern and eastern parts of Japan, such as Hokkaido, Tohoku, and Kanto (including Niigata Prefecture), where climate change will cause an increase in the total factor productivity of rice. However, the western region will benefit, despite the decrease in production, and consumer surplus in most regions will increase. As such, the impacts of climate change are complicated and differ by region. To consider policy countermeasures against climate change, the CGE model can provide useful information.

Discipline: Agricultural Economics

Additional key words: crop-growth model, global climate model, hydrological model, recursive-dynamic regional CGE model, total factor productivity (TFP)

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Introduction

Agriculture is highly dependent on climate conditions, such as temperature, solar radiation, and precipitation, so future climate change will affect food production and may make food supplies vulnerable. Stern (2006) predicted that agriculture in countries at higher latitudes would likely benefit from a moderate level of warming (2–3° C), but that even a small amount of climate change in tropical regions would cause yields to decline. Japan is located at a relatively high latitude, so it is possible that Japanese rice production may benefit from future climate change. However, an increase in yield does not necessarily mean an economic benefit. To measure the economic effects of climate change, we need to evaluate changes in price and quantity with considering market conditions. In this sense, a comprehensive evaluation of the impact of climate change on the rice sector in Japan is important, both for making policy decisions and from an academic interest point of view (Watanabe and Kume, 2009).

Changes in crop yields can be measured by field experiments and by using the objective results of the crop-growth model based on biology. However, evaluating changes in the quantity and price of agricultural products requires an economic model. Partial equilibrium models can measure such changes, but they assume that agricultural markets do not affect the rest of the economy (i.e., they are treated as exogenous). The computable general equilibrium

(CGE) model can depict inter-market relations and trade flows for the economy as a whole, including the circular flow of income and expenditure. Therefore, they are better suited to analyzing global effects on agricultural markets, as is the case with climate change (Palatnik and Roson, 2011). Many previous studies have used the CGE model to analyze the effects of climate change in Europe, the USA, and developing countries, as shown in the next section. However, few CGE studies have evaluated the impact of climate change on the Japanese rice sector.

The present study uses the CGE model to comprehensively evaluate the influence of future climate change on Japan's rice sector and regional economies. The features of this study are as follows: (i) the recursive-dynamic regional CGE model is used to capture regional differences in climate change; (ii) direct effects of climate conditions on rice productivity are estimated using the crop-growth model and the hydrological model, in addition to the global climate model (GCM), Model for Interdisciplinary Research on Climate (MIROC); (iii) farmland is introduced into the model to consider restrictions on natural resources; and (iv) the rice sector is separated from the agricultural sector, which is usually one aggregated sector in the Japanese inter-regional input-output table, to enable us to specifically study the effects on the rice sector.

Section 2 of the paper provides an overview of previous studies that have examined the economic effects of climate change on agriculture. Section 3 explains the structure of the CGE model, the data, and the simulation method used to measure the influences of climate change. Section 4 presents the results of the simulation based on the CGE model. Finally, Section 5 concludes the paper, and discusses the possible policy implications resulting from the analysis.

Literature review and scientific question

Furuya and Koyama (2005) analyzed the influences of climate change using the global econometric model. The rice yield function was estimated by considering temperature and precipitation during the rice maturation period. Their results showed that a rise in future temperatures, as a result of global warming, would increase rice production in most Asian countries, including Japan. Their model assumed a linear influence of climate factors on production levels, but the biology-based crop model has shown that climate factors affected rice production in a non-linear way (Yokozawa, 2009; Iizumi, 2009). In other words, effects of climate condition change from being positive to negative at a threshold value depending on plant growth. Including such non-linear effects is important for useful long-term predictions.

Kunimitsu et al. (2013) estimated regression functions of total factor productivity for Japanese rice production, including several causative factors such as socio-economic factors and climate conditions. In their model, the potential impact of climate factors is shown by the elasticity values of rice total factor productivity (TFP). Their results show that (i) the potential impact of temperature and solar radiation via crop yield was high next to the economies of scale represented by farm management scale per farm organization, and that (ii) climate factors in addition to socio-economic factors cause regional gaps in rice TFP to increase over time. Considering these features, we attempt to show how future climate change would influence Japanese rice production and price by analyzing the rice market.

The CGE model has used market information to analyze agricultural production and trade liberalization, as well as to run policy simulations. Saito (2002) analyzed the effects of a farmland consolidation project on agricultural production. Kunimitsu (2009) measured the economic effects of irrigation and drainage facilities on Japanese agriculture. The CGE models used in these studies were static models. Bann (2007) and Masui (2005) used the dynamic CGE model, but they did not use precise agricultural sectors and farmland as factors of production in the model. In order to evaluate long-term climate change, the dynamic feature needs to be installed in the CGE model.

With regards to CGE analyses of climate change, Lee (2009) quantitatively analyzed the impact of climate change on global food prices and quantities by using a multi-sector CGE model. Similar to Stern (2006), his analysis showed that climate change benefited the crop yield of developed countries. Calzadilla (2011) also used a CGE model to analyze the effects of climate change on agriculture in view of water use. In particular, they focused on climate change and trade liberalization, and analyzed global agricultural production. Their results showed that, although future climate changes will cause global agricultural production to decrease as a result of water use, Japan and some countries may be able to increase production. Trade liberalization reduced the negative impact of climate change on the welfare level. In addition, it tended to reduce the use of water use in water scarce regions and increase the use of water use in water abundant regions, all without using water market mechanisms. However, in most previous analyses, the world economy was classified into a few regions, with Japan merged with OECD countries such as the USA, Western Europe, and Australia. These broad classifications make it very difficult to determine how the changes impact Japanese agriculture. Therefore, a detailed multi-regional CGE model is needed to accurately and effectively analyze rice production in Japan.

As shown in the above previous studies, CGE models have great potential as a way to evaluate the effect of future climate change on agriculture by considering price and quantity in the market. Since previous CGE analyses have rarely been applied to the issue of climate change and the Japanese rice market, it will be interesting to evaluate whether future climate change is beneficial or detrimental to Japanese rice production.

Method

1. Structure of the recursive-dynamic regional CGE model

The model used here is the recursive-dynamic CGE model, with multiple regions. The structure of our model is based on the work of Bann (2007), which uses GAMS (GAMS Development Corporation) and MPSGE (a modeling tool using the mixed complementary problem), as developed by Rutherford (1999). The GAMS code of the model is shown in the APPENDIX. The major modification points of this model are as follows.

The cost functions derived from the production functions are defined as nested-type CES (constant elasticity of substitution) forms. Figure 1 shows the structure of the cost function. The parameter (*s*) represents the substitution elasticities, and the values are set to the same as those used by Bann (2007). The elasticity of substitution of farmland to other input factors, which was not used in Bann (2007), is assumed to be 0.1 for agriculture. Egaitsu (1985) concluded that the substitutability of farmland for other input factors was low, but the substitutability between capital and labor was high, according to empirical evidence on Japanese rice production from several studies. Based on these findings, we assumed that farmland is a semi-fixed input for agricultural production and cannot really be substituted by other factors.

$TFP_{r,t}$ and TFP_0 in the production functions refer to the total factor productivity in year t and the substantial level ($TFP_0 = 1$ in this study), respectively. With respect to climate change, *TFP* varies per year, and this factor is defined in previous studies as follows (Kunimitsu, 2013):

$$TFP_{r,t} = \beta_0 \cdot {MA_{r,t}}^{\beta_1} \cdot {KK_t}^{\beta_2} \cdot {CHI_{r,t}}^{\beta_3} \cdot {CQI_{r,t}}^{DR_r \cdot \beta_4} \cdot {CFI_{r,t}}^{\beta_5} \qquad (1)$$

Here, *MA* is the management area per farmer, representing economies of scale, and *KK* is knowledge capital stocks accumulated through research and development (R&D) investments. *CHI*, *CQI*, and *CFI* are the crop-yield index, crop-quality index, and flood index, respectively. The β*'s* represent the coefficients estimated from the panel data regression analysis, with $\beta_0 = -2.7014$, $\beta_1 = 0.3285$, $\beta_2 = 0.0590$, $\beta_3 = 0.1824$, $\beta_4 = 0.0863$, and $\beta_5 = -0.0277$. *DR* is a dummy variable, taking the value 1 for Hokkaido, and 0 otherwise. As explained in Kunimitsu et al.

(2013), *CHI*, *CQI*, and *CFI* are also defined by the crop-growth model, crop-quality model, and hydrological model with using climate conditions, such as temperature, solar radiation, and precipitation.

< Fig. 1 >

Consumption is defined by the CES function with a substitution elasticity of 0.5 (see Figure 2). The elasticity values of substitution in the consumption, import, and export functions are set to be the same as those used by Bann (2007), which were based on the GTAP database. The government consumption and government investment (Figs. 3) are Leontief type fixed share function.

< Fig. 2, Fig. 3 >

To form the recursive dynamic path, the capital stock equation is defined by annual investment (*I*) and disposable rate (δ= 0.04), as follows.

$$\overline{K}_{r,t} = (1-\delta)\overline{K}_{r,t-1} + I_{r,t} \qquad (2)$$

In this model, $\overline{K}$ shows capital supply and is defined for every year from *I*, which is endogenously defined by the CGE model.

2. Data and simulation method

To calibrate the parameters of the model, the social accounting matrix (SAM) was estimated on the basis of Japan's 2005 inter-regional input-output table. To analyze rice production more precisely, the rice sector was separated from the aggregated agriculture, forestry, and fishery sectors in the IO table, based on regional tables (404 × 350 sectors). Then, the sectors were reassembled into 14 sectors: rice; other agriculture, forestry, and fishery; mining and fuel; food processing; chemical products; general machinery; electric equipment and machinery; other manufacturing; construction; electricity and gas; wholesale and retail sales; financial services; and other services. Regions were also reassembled into eight regions:

Hokkaido; Tohoku; Kanto, including Niigata Prefecture; Chubu; Kinki; Chugoku; Shikoku; and Kyushu, including Okinawa.

The factor input value of farmland, which was not shown in the Japanese I/O Table, was estimated using farmland cultivation areas (Farmland statistics, Ministry of Agriculture, Forestry, and Fishery, and every year) and multiplying the areas by farmland rents. Then, the farmland factor input value was subtracted from the operation surplus in the original IO table. The value of capital input was then composed of the rest of operation surplus and the depreciation value of capital.

To simulate the macroeconomic impacts of climate change, we considered the following cases.

CASE 0: This case represents a situation of business as usual (BAU), and is used as a base line. In this case, farmland supply and labor supply in each region were fixed at the present levels shown in the SAM data. The technological growth rate of the Japanese economy was assumed to be 0 so as to show only the effects of climate change. The *TFP* of rice production was also set to 1, showing no progress in technology and no change in climate conditions.

CASE 1: This case represents future climate change that only affects rice production. The exogenous variables other than *TFP* were set to the same values as in CASE 0. Future rice *TFP* levels were calculated using Eq. (1), as shown in Figure 4. These *TFP*s include the influence of both socio-economic factors (*MA* and *KK*) and climate factors (*CHI*, *CQI*, and *CFI*). To simulate the pure effect of the climate factors, the *TFP* in each region was divided by $TFP' = f(MA, KK)$, which shows *TFP* changes resulting only from socio-economic factors, with the same estimated coefficients as Eq. (1) (see Figure 5). Changes in climate factors were predicted using the crop-growth model, crop-quality model, and hydrological model, along with the projection results of MIROC, high-resolution version 3.0 (K-1 Model Developers, 2004). The greenhouse gas emission scenario was A1B which shows balanced growth with rapid economic growth, low population growth, and the rapid introduction of more efficient technology in the Special Report on Emission Scenario (SRES) (Nakicenovic and Swart, 2000).

< Fig. 4, Fig. 5>

Results

To ensure the stability of the simulation results, a sensitivity analysis was conducted by changing the substitution elasticities of demand and inter-regional material demand as intermediate inputs. The degree of impact changed, but the directions of the changes were the same for all variables. Therefore, the results presented below are reasonably stable and common, as long as there is no change to the economic structure.

1. Rice production

Figure 6 shows chronological changes in rice production, estimated using the CGE model with *TFP* changes. Although the exogenous variables were set as the status quo, rice production in CASE 0 increased as a result of an increase in capital stocks, which were endogenously accumulated by annual investment. Hence, the difference between CASE 1 and CASE 0 shows only the effects of changes in climate factors.

In accordance with the *TFP* changes shown in Figure 5, climate change increased rice production in the north and eastern regions, such as Hokkaido, Tohoku, and Kanto (including Niigata Prefecture). However, rice production decreased in the western regions, such as Kinki, Chugoku, Shikoku, and Kyushu. Annual production fluctuated under climate change, but the average growth rates in Tohoku and Kanto were higher than other regions, so the scale of vertical axis in these regions was double that of the other regions. In these two regions, rice production amount was relatively large, so there were some capacities for the economies to allocate production resources to other sectors. In contrast, the growth rates of rice production in Kinki and Shikoku were low, because rice production in these two regions was small in comparison to other agricultural sectors and other industries.

Even in the north and eastern regions, production levels fell below the CASE 0 level in some years, with the exception of Hokkaido. Rice production in Hokkaido benefitted in all years, even under bad climate conditions. The western regions experienced worse production than CASE 0 in many years, but the difference between CASE 1 and CASE 0 fluctuated over time. This degree of fluctuation degree increased after 2050. Until then, climate conditions tended to increase the crop yield, but decrease crop quality. However, from the 2050s onwards, when temperatures were frequently beyond the threshold level, climate conditions decreased both crop yield and crop quality, showing agglomeration effects. Tohoku, Kanto, and Kyushu showed wider fluctuations in production, because their rice production amounts were larger than other regions. In the western regions, the decreases in crop yield and crop quality became serious during the latter period of the simulation, largely because of negative agglomeration effects of temperature to rice *TFP* via rice yield and quality.

Table 1 shows the sum of the annual production figures from 2005 to 2100. The northern and eastern regions show positive production amounts, and can increase their total production beyond that of CASE 0. The increase in production accelerated in these regions in the latter period of the simulation. On the other hand, climate change had a negative effect on the western regions, and these effects became stronger in the latter part of the simulation period because of above-mentioned agglomeration effects of temperature. From these results, it is clear that the effects of climate change on rice production differ according to location.

Figure 7 shows price changes in the rice sector resulting only from climate change. In contrast to production quantity, the price of rice decreased in the northern and eastern regions, but increased in the western region. Since rice consumption does not really increase, even after a decrease in price, the price dropped in those regions where production increased, but rose in those regions where production decreased. This is because price elasticity of rice demand is low, which is common in food, and an imbalance in supply and demand is reflected in a sharp change in price. Such situations may be similar in other agricultural sectors, but no climate simulations were conducted for any other sectors.

< Fig.6, Fig.7, Table 1 >

2. Prices of input factors and farmers' income

Table 2 shows factor price changes in the rice sector. The directions of the changes in factor prices were the same as those of the rice prices in all regions. That is, the northern and eastern regions, where the rice price decreased, experienced a decrease in factor prices, and the western regions experienced an increase in factor prices. Changes in farmland rental rates were larger than other factors, because we assumed that substitution elasticity of farmland to other factors was low. In addition, farmland is immobile, and used only for agriculture, so rice price changes in production within the region directly affect farmland rental values.

Table 3 shows sum of the rice farmers' income (deflated by consumer price index), as affected by rental rate, wage, and capital service price. The same trends were evident in both agricultural farmers' income including other agricultural sectors, and rice farmers' income excluding capital depreciation value. However, these results were omitted here because of a limit in space.

Farmers' income decreased in the northern and eastern regions, where rice production increased after the climate change, but farmers' income in the western regions (decreased rice production) increased. This happened as a result of rice price changes, which changed in the opposite direction to the changes in rice production. In other words, the degree of price changes was larger than the degree of production changes.

Farmers’ income across the whole country decreased as a result of the climate change. This negative impact on overall income also became more serious in the latter period of the simulation. Therefore, overall, climate change does not benefit farmers.

< Table 2, Table 3 >

3. Gross regional production and social welfare

Table 4 shows the sum of gross regional production (GRP) during the simulation periods. In contrast to farmers’ income changes, changes in GRP were positive in Kanto and Chubu. Kanto and Chubu have sizeable manufacturing industries, so the demand for manufacturing and service goods, which could increase by a shift of production factors from rice sector after the increase in rice *TFP*, became concentrated in these regions. Overall, the total GRP for the country increased after the climate change. However, Chugoku and Shikoku experienced minor losses in GRP after the climate change, because the manufacturing sector is relatively weak in these regions.

Table 5 shows the sum of the equivalent valuation (EV) corresponding to the consumer surplus and the social welfare level. The EV in most regions increased after the climate change, and even Chugoku and Shikoku, where the GRP effects were negative, experienced an increase in welfare. The difference between EV and GRP is mostly reflected in income effects, so the negative income effects overwhelmed the substitution effects caused by the climate change in these regions. The EV in Hokkaido and Tohoku became negative, but such negative effect was much smaller than negative effect in income. Therefore, social welfare levels of non-farmers increased in these regions, although it could not overcome farmers' income loss. Overall, the EV change for the country as a whole was positive; therefore, climate change benefits Japanese consumers.

< Table 4, Table 5 >

Discussion and conclusion

This study used the CGE model to comprehensively evaluate the influence of future climate change on Japan's rice sector and regional economies. We built the recursive-dynamic CGE model using multiple regions associated with the crop-growth model, crop-quality model, and hydrological model. This CGE model was used to simulate the future impact of climate change. Based on our simulation results, there are several policy implications.

First, future climate change increases rice production for the country as a whole, but causes rice prices to decrease. As a result of these reverse effects, farmers' income in the rice sector decreases, despite the increase in production amount. This happens because of the inelastic demand for rice, which does not increase very much, even after a decrease in price. In the northern and eastern parts of Japan, such as Hokkaido, Tohoku, and Kanto (including Niigata Prefecture), rice production increased after the climate change, but rice prices and farmers' income decreased. In contrast, the western regions experienced an increase in price and income after the climate change, despite the decrease in production. Therefore, climate change benefits regions where the total factor productivity for rice decreases in extremely high temperatures. These effects are somewhat counterintuitive, as they show that farmers' income cannot be improved in the area where climate change primarily increases rice *TFP*. In the real data, such effects of climate change may be too small to observe, because the Japanese rice sector is small when compared to other industries. Of course, such effects are highly dependent on the parameter values, such as substitution elasticities, in the CGE model. Therefore, it is important to use an economic model for policymaking and to quantify the parameters using econometric methods and precise data.

Second, the GRP and social welfare level measured by the EV change may improve after

based on the most recent published I/O table, so using more recent data is necessary. It is hoped that new I/O data will soon be available. Third, because of computational ability and the model structure, the CGE model used here has 14 sectors and 8 regions. Improving the model structure to handle more precise sectors and regions is important. In addition, other possible future tasks are to analyze the effects of climate change on other agricultural sectors, forestry, and fishery, to measure the effects by considering trade liberalization, and to evaluate policy instruments against future climate change.

Appendix

The CGE model used here were composed by using GAMS with MPSGE solver. The syntax of MPSGE is shown in Rutherford (1999). In equations, suffixes of *i* and *j* show sector classification, suffixes of *p* and *r* show regions. Variables used in the model are explained in Table A-1.

```
*==================================================================
*     MPSGE model
*==================================================================
$ontext
$model:MRM_jpn

$sectors:
  X(i,r)                      ! Production
  XV(i,r)                     ! Value added production
  XA(i,r)                     ! Armington aggregate
```

```
   M(i,r)$M0(i,r)           ! Import
   E(i,r)$E0(i,r)           ! Export
   CP(r)                    ! Household consumption
   CG(r)                    ! Government consumption
   IG(r)                    ! Public investment
   IP(r)                    ! Private investment
$commodities:
   PV(i,r)                  ! Price of value added production
   PD(i,r)                  ! Price of output for domestic use
   PA(i,r)                  ! Price of armington aggregates
   PM(i,r)$M0(i,r)          ! Price of import goods
   PE(i,r)$E0(i,r)          ! Price of export goods
   PCP(r)                   ! Price of consumption
   PCG(r)                   ! Price of government consumption
   PIG(r)                   ! Price of public investment
   PIP(r)                   ! Price of private investment
   PL(r)                    ! Wage rate
   PK(r)                    ! Capital service price
   PF(r)                    ! Farmland price
   PFX                      ! Foreign exchange
$consumers:
   HA(r)                    ! Household agent
   GOV(r)                   ! Government


$prod:XV(j,r)     s:0.1     va1:0.8   va2(va1):0.8
```

```
   o:PV(j,r)          q:(XV0(j,r)*TFP(j,r))

   i:PF(r)$F0(j,r)    q:F0(j,r)           p:PF0(r)

   i:PL(p)            q:L0(j,p,r)         p:PL0(p)            a:GOV(p) t:taxl(p)            va1:

   i:PK(p)            q:K0(j,p,r)         p:PK0(p)            a:GOV(p) t:taxk(p)            va2:

$prod:X(j,r)$E0(j,r)    t:2    s:0.1

   o:PD(j,r)          q:XD0(j,r)          p:PX0(j,r)          a:GOV(r) t:taxy(j,r)

   o:PE(j,r)          q:E0(j,r)           p:PX0(j,r)          a:GOV(r) t:taxy(j,r)

   i:PA(i,p)          q:IO0(i,j,p,r)

   i:PV(j,r)          q:XV0(j,r)

$prod:X(j,r)$(not E0(j,r))     s:0.1

   o:PD(j,r)          q:X0(j,r)           p:PX0(j,r)          a:GOV(r) t:taxy(j,r)

   i:PA(i,p)          q:IO0(i,j,p,r)

   i:PV(j,r)          q:XV0(j,r)

$prod:XA(j,r)        s:2

   o:PA(j,r)          q:XA0(j,r)

   i:PD(j,r)          q:XD0(j,r)

   i:PM(j,r)          q:(-M0(j,r)-TM0(j,r))

$prod:M(i,r)$M0(i,r)

   o:PM(i,r)          q:(-M0(i,r)-TM0(i,r))

   i:PFX              q:(-M0(i,r))        p:PM0(i,r)          a:GOV(r) t:taxm(i,r)

$prod:E(i,r)$E0(i,r)

   o:PFX              q:E0(i,r)

   i:PE(i,r)          q:E0(i,r)

$prod:CP(r)          s:0.5

   o:PCP(r)           q:CP0(r)
```

```
    i:PA(i,p)          q:CPS0(i,p,r)
$prod:CG(r)            s:0
    o:PCG(r)           q:CG0(r)
    i:PA(i,p)          q:CGS0(i,p,r)
$prod:IG(r)            s:0
    o:PIG(r)           q:IG0(r)
    i:PA(i,p)          q:IGS0(i,p,r)
$prod:IP(r)            s:0.5
    o:PIP(r)           q:IP0(r)
    i:PA(i,p)          q:IPS0(i,p,r)
$demand:HA(r)
    d:PCP(r)           q:CP0(r)
    d:PIP(r)           q:IP0(r)
    e:PL(r)            q:LS0(r)
    e:PK(r)            q:(KS(r)*rk(r))
    e:PF(r)            q:FS0(r)
    e:PCG(r)           q:SG0(r)
    e:PFX              q:(-SF0(r))
    e:PCP(rnum)        q:(-TRF0(r))
$demand:GOV(r)
    d:PCG(r)           q:CG0(r)
    d:PIG(r)           q:IG0(r)
    e:PCG(r)           q:(-SG0(r))
$offtext
$sysinclude mpsgeset MRM_jpn
```

< Insert Table A-1 >

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